

Keck Adaptive Optics Note 716

Next Generation Adaptive Optics Preliminary Design Wavefront Error Budgets

Richard Dekany, COO

Contributions from: Antonin Bouchez, COO; Mitchell Troy, JPL; Chris Neyman and Peter Wizinowich, CARA, and Liz McGrath, Claire Max, and Don Gavel, UCO/Lick

May 12, 2010

Abstract

The purpose of this note is to summarize the wavefront error and encircled energy budgets for the Next-Generation Adaptive Optics (NGAO) system at the time of the NGAO Preliminary Design Review.

These budgets are based upon a set of architecture design choices and functional requirements flowdowns consistent with the NGAO System Requirements, which are maintained in an online Requirements Management database product, Contour, developed by JAMA Software, Inc. and commercially licensed by W.M. Keck Observatory.

Revision Sheet

Release No.	Date	Revision Description
Rev 1.0	5/12/10	Initial release

Table of Contents

\boldsymbol{A}	bstraci	<i>t</i>	<i>1</i>
R	evisioi	n Sheet	2
1		roduction	
	1.1	Acronyms and Definitions	
	1.2	Purpose	
	1.3	Scope	
		-	
	1.4	Related Documents	
	1.4.	· · · · · · · · · · · · · · · · · · ·	
	1.4.		
	1.4.	4 References	7
2	Bac	ckground	8
	2.1	High-angular Resolution Science Priority	8
3	Per	rformance Requirements Development and Flow-down	8
	3.1	Build-to-Cost Architecture Changes and Performance Revisions	8
	3.2	Requirements Capture Process	9
	3.3	Wavefront Error Requirements Summary	13
	3.4	High-Contrast Requirements Summary	
	3.5	Astrometric Precision Requirements Summary	14
4	NG	SAO Science Cases	15
5	KA	ON 721, "Wavefront Error Budget Tool"	16
	5.1	Introduction	
	5.2	"Input Summary" Sheet	
	5.3	Optimization ("Optim") Sheet	
	5.4	Encircled / Ensquared Energy ("EE") Sheet	
	5.5	Wavefront Error Budget Terms	
	5.5.		
	5.5.		
	5.5.		
	5.5.		
	5.6	"Sky Coverage" Sheet	
	5.7	Wavefront Error Budget Validation	
	5.7. 5.7.		
	5.8	Configuration Control	
6		tailed Error Rudget for Galaxy Assembly Key Science Case	32

	6.1	Science Path Wavefront Error Budget	32
	6.2	TT Sharpening Budget	35
	6.3	TWFS Budget	36
7	Gai	laxy Assembly Case Performance Sensitivities	36
	7.1	LGS Performance vs. Seeing	36
	7.2	LGS Performance vs. Wind Speed	37
	7.3	LGS Performance vs. Laser Return	38
	7.4	LGS Performance vs. Sky Fraction	39
	7.5	LGS Performance vs. LO WFS Passband	40
	7.6	LGS Performance vs. Spaxel Size	41
	7.7	LGS Performance vs. Number of LO WFS NGS	42
	7.8	NGS Performance vs. Natural Guide Star Brightness\	42
	7.9	Interferometer Performance vs. Natural Guide Star Brightness	42
	7.10	Monte Carlo Error Budget Modeling Results	42
	7.11	LAOS Simulation Modeling Results	45
8	NG	AO Science Cases Performance Summaries	45
	8.1	Performance Summary	45
	8.2	Science Path WFE using NGS WFS in TWFS mode	47
A_{j}	ppendi	x A: Key Science Case Detailed Error Budgets	48
		y Assembly	
	Nearb	y AGN	50
	Galac	tic Center Imaging	51
	Galac	tic Center Spectra	52
	Ехо-р	lanets	53
	Minor	· Planets	54
	Io		55
	QSO	Host Galaxies	56
	Gravi	tational Lensing	57
	Astro	metry Science	58
	Trans	ients	59
	Resolv	ved Stellar Populations	60
	Debris	s Disks and YSOs	61
	Gas G	iant Planets	62
	Ice Gi	ant Planets	63

Appendix B:	Atmospheric	Turbulence.	Assumptions	64
-------------	-------------	-------------	-------------	----

1 Introduction

1.1 Acronyms and Definitions

DAVINCI A new science instrument under development as part of NGAO

DD Detailed Design
EncE Encircled Energy
EnsqE Ensquared Energy

FoV Field of View (the field observed by a single detector array)
FoR Field of Regard (the technical or patrol range of a sensor)

FWHM Full-Width at Half-Maximum = 2.355σ , for a Gaussian distribution

HO WFS High-order wavefront sensor IFU or IFS Integral Field (Unit) Spectrograph

LGS Laser Guide Star

LO WFS Low-Order Wavefront Sensor

mas Milliarcseconds

NGAO Next-Generation Adaptive Optics

NGS Natural Guide Star

NGWFC Next-Generation Wavefront Controller

PD Preliminary Design
PSF Point Spread Function
RMS Root Mean-Squared

SD System Design

TT Tip-tilt

TWFS Truth Wavefront Sensor

WFE Wavefront Error
" arcseconds
' arcminutes

1.2 Purpose

The purpose of this document is to describe the expected wavefront error performance of NGAO, the methodology for constructing and maintaining NGAO error budgets, and to investigate the robustness of NGAO performance to various changes in input assumptions.

1.3 Scope

This document includes all defined NGAO science case error budgets, sample TT sharpening budgets, and numerous trade studies performed to capture NGAO performance sensitivities to environmental, observational, and technical assumptions. We include a summary of the assumptions, architecture choices, performance flowdown requirements, validation results, external comparisons, and other supporting materials for our performance estimates.

1.4 Related Documents

1.4.1 Configuration-Controlled Documents

- KAON 550, NGAO System Configurations
- KAON 636, Observing Operations Concept Document
- KAON 642, Design Changes in Support of Build-to-Cost
- KAON 721, Wavefront Error Budget Tool
- KAON 722, NGAO High-Contrast Error Budget Tool
- KAON 723, Performance Flowdown Budgets

1.4.2 Previous NGAO Performance Documents

- KAON 452, MOAO versus MCAO Trade Study Report
- KAON 465, NGAO LGS Wavefront Sensor: Type and Number of Subapertures Trade Study
- KAON 470, NGAO Sky Coverage Modeling
- KAON 471, NGAO Wavefront Error and Ensquared Energy Budgets (for System Design Phase)
- KAON 475, Tomography Codes Comparison and Validation for NGAO
- KAON 480, Astrometry for NGAO
- KAON 492, NGAO Null-Mode and Quadratic Mode Tomography Error
- KAON 497, NGAO High-Contrast and Companion Sensitivity Performance Budget
- KAON 503, Mauna Kea Ridge Turbulence Models
- KAON 504, NGAO Performance vs. Technical Field of View for LOWFS Guide Stars
- KAON 594, Plan to Address Phased Implementation and Descope Options
- KAON 601, NGAO Point and Shoot (SPIE 2008)
- KAON 621, Noise Propagator for Laser Tomography AO
- KAON 629, Error Budget Comparison with NFIRAOS
- KAON 635, Point & Shoot Study
- KAON 644, Build-to-Cost Architecture Performance Analysis
- KAON 686, Laser Launch Facility System Performance
- KAON 710, Latency, Bandwidth, and Control Loop Residual Relationships

1.4.3 Keck AO Performance Analyses

- KAON 461, Wavefront Error Budget Predictions & Measured Performance for Current & Upgraded Keck AO
- KAON 462, NGAO Trade Study: Keck AO Upgrade
- KAON 469, Effect of Keck Segment Figure Errors on Keck AO Performance
- KAON 482, Keck Telescope Wavefront Error Trade Study
- KAON 500, Keck AO Upgrade Feasibility

1.4.4 References

- "The W. M. Keck Observatory Scientific Strategic Plan 2009", W. M. Keck Observatory.
- CIN 626, PALM-3000 Error Budget Summary
- J. W. Hardy, Adaptive Optics for Astronomical Telescopes (Oxford U. Press, 1998).
- KAON 416, Atmospheric Sodium Density form Keck LGS Photometry
- KAON 427, Variable versus Fixed LGS Asterism
- KAON 465, NGAO LGS Wavefront Sensor: Type and number of Subapertures Trade Study
- KAON 477, Modeling Low Order Aberrations in Laser Guide Star AO Systems (OE 2007)

- KAON 478, Modeling Laser Guide Star Aberrations (OSA 2007)
- KAON 662, Beam Transport Optics
- KAON 685, Opto-mechanical Design
- KAON 692, LGS Wavefront Sensor Preliminary Design
- KAON 695, Beam Generation System
- KAON 704, Opto-mechanical Registration Tolerances for "go-to" Adaptive Optics
- KAON 708, Limit to AO Observations from Altitude-Azimuth Telescope Mounts.
- KAON 718, NGAO LGS and NGS Wavefront Sensor Cameras
- KAON 729, Natural Guide Star Wavefront Sensor

2 Background

2.1 High-angular Resolution Science Priority

W. M. Keck Observatory, through a series of science strategic planning exercises beginning at least as early as 2003, and again revised in November 2005, Fall 2008, and Spring 2009, has steadfastly maintained "High Angular Resolution Astrophysics" as one of four top priorities that define the Keck Strategic Mission. As the top-ranked initiative in the scope of project over \$20M, the 2009 Plan specifically note the scientific premium upon NGAO

"obtaining the highest spatial resolution possible and also visible band capability" (pg. 5)

The Plan further identifies the following key new capabilities for NGAO:

"Near diffraction-limited observations in the near-IR (K-Strehl ~80%); AO correction at red wavelengths (0.65-1.0mm); Increased sky coverage; Improved angular resolution, sensitivity, and contrast; Improved photometric and astrometric accuracy, Imaging and integral field spectroscopy." (pg. 22)

Within this context, the NGAO project has undertaken a series of performance budget developments in the system design (SD) and preliminary design (PD) phases that are intended to:

- 1. Facilitate the capture of high-level system requirements
- 2. Support the flow-down of system requirements to functional requirements imposed upon individual NGAO subsystems
- 3. Assess technical and cost tradeoffs across the project
- 4. Identify and support management of project technical risk areas
- 5. Support science team development of predictive NGAO science models and observing scenarios.

3 Performance Requirements Development and Flow-down

3.1 Build-to-Cost Architecture Changes and Performance Revisions

Subsequent to the System Design Review (SDR), revisions to the system architecture were necessitated by new sponsor guidance of a cost-capped funding envelope for NGAO, known as Build-to-Cost (B2C). This necessitated cost-saving architectural changes, which were documented in KAON 642, Design

Changes in Support of Build-to-Cost. A "delta-assessment" of the B2C changes on system wavefront error performance was performed in KAON 644, Build-to-Cost Architecture Performance Analysis, which provided sufficient confidence on the ultimate ability of NGAO to deliver its primary science objectives. An external review panel agreed with this assessment, as described in KAON 650, Build-to-Cost Reviewer Report, allowing us to proceed with the remainder of the PD phase. For the systems engineering group, this included capture of key performance flowdown requirements, improved analysis of key error budget terms, and refinement of science cases.

3.2 Requirements Capture Process

Early in the SD phase, the NGAO project developed a strategy for the interpretation of science-based requirements, as captured in KAON 455, "Science Case Requirements Document", into NGAO performance requirements. This process is described in Figure 1. It is based upon the development of a number of distinct NGAO science cases, the identification of key science drivers (i.e. the science requirements that force the architecture and performance of the system), the evaluation of these drivers against evolving performance models (engineering models and/or wave optics simulations), and the iterative adoption of a self-consistent set of science-driven performance requirements and system architecture choices.

NGAO Science Requirements / Performance Budget Process

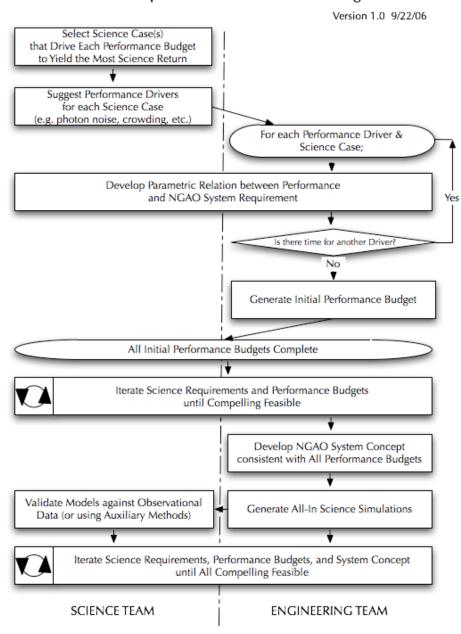


Figure 1. Performance requirements development process

For our System Design Review (SDR), this process had supported both the NGAO architecture downselect process (KAON 499, "NGAO System Architecture Definition"), and generated the following performance budgets:

- Wavefront Error and Ensquared Energy
- Photometric Precision
- Astrometric Accuracy
- High-Contrast

- Transmission and Background
- Polarimetric Precision
- Observing Efficiency
- System Uptime

The SD phase development of these budgets is documented in KAON 491, "NGAO system performance summary".

After our SDR was held in April 2008, new sponsor guidance to proceed with a cost-capped re-scoping of the project (aka "Build-to-Cost") required reiteration of the process in Figure 1. Upon the establishment of the cost-saving changes described in KAON 642, "Design Changes in Support of Build-to-Cost", the performance budgets were partially reevaluated in KAON 644, "Build-to-Cost Architecture Performance Analysis". Based on KAON 644, additional feedback from the science team was received.

As a result of the initial SD phase reports from individual working groups addressing each performance budget, combined with the compressed budget and schedule induced by the Built-to-Cost project rescope, NGAO senior management curtailed further development of performance budgets for both Photometric Precision (KAON 474, "AO Photometry for NGAO") and Polarimetric Precision, although polarization issues have been considered for Keck Interferometer support (KAON 428, "Implications and Requirements for Interferometry with NGAO"; KAON 748, "NGAO & the Keck Interferometer".)

For reference the historical transition of the performance requirements, including current Keck AO Performance as documented in KAON 461, is shown in

Table 1. In general, the imposed cost cap has resulted in the performance degradation of some science cases, but the close iterations between technical and science teams on science priorities has allowed performance improvement for certain key science cases.

NGAO Key Science	2006 Keck 2 AO Performance in 75 th	Expected Keck 1 AO Performance in		GAO Requ in Median		
Case	Percentile Best Seeing (approx.)	Median Seeing (approx.)	Proposal ^{1,2}	SDR	B2C	PDR
Galaxy Assembly	557 ³	529 ⁴	197 ⁵	257	204	185
Nearby AGN's	557 ³	529 ⁴	197 ⁵	N/A	182	181 ⁶
Galactic Center	401 ⁷ in median seeing	387 ⁸	182	184	189	193
Exoplanets	378 ⁹	311 ¹⁰	N/A	155 ¹⁰	171	174
Minor Planets	557 ³	529 ⁴	131	175	177	181 ¹¹
lo	258 ¹²	210 ¹³	125	148 ¹³	N/A	117

Table 1. Progression of Wavefront Error Performance Requirements to Date (Proposal = Project Initiation (June 2006); SDR = System Design Review (April 2008); B2C = Built-to-Cost (Aug 2008), PDR = Preliminary Design Review (June 2010), N/A = Not available).

During the NGAO preliminary design (PD) phase, as the initial high-level performance requirements were flowed down to subsystems and design decisions and constraints informed the maturity of the design, there has been additional iterations between the technical and science teams. In parallel, based on additional thinking of the observing scenarios and science objectives, revisions to the Key Science Cases have been provided (Max and McGrath, KAON in preparation).

One outcome of the PD phase flowdown and pushback process was the tightening of the residual non-common-path and telescope jitter tip-tilt error requirements. At the same time, higher galactic latitude

¹ Slight revisions to the Key Science Cases have been made during PD phase. See McGrath and Max, "Science Case Parameters for Performance Budgets" for more details.

² June 20, 2006 NGAO Design and Development Proposal, Table 13.

³ KAON 461, Table 1 for LGS mode with 18th magnitude TT star.

⁴ KAON 461, Appendix 3 for LGS mode with 18th magnitude TT star.

⁵ June 20, 2006 NGAO Design and Development Proposal, Figure 49, for 30% sky coverage, z = 30 deg, having 173 nm HO error and

⁶ Performance increase driven by reduced FoR for this science case brought on by Build-to-Cost decision to eliminate a d-IFU instrument from the NGAO program.

⁷ Jessica Lu, private communication, who reports NGWFC *median* performance of 401 nm RMS, or a K-Strehl of $^{27\%}$ (75th percentile performance not available). This is broadly consistent with the report K-Strehl of 30% in Ghez, et al., *Astrophys. J.*, 635:1087-1094, 1995.

⁸ Here, we assume Keck 1 LGS will provide the same high-order wavefront error improvement at GC as shown in KAON 461, Table 2, LGS case, namely the subtraction of 105 nm in quadrature, so $sqrt(401^2 - 105^2) = 387$ nm. ⁹ KAON 461, Table 1 for LGS mode with 10^{th} magnitude TT star.

 $^{^{10}}$ KAON 461, Appendix 2 for LGS mode with $10^{t\bar{h}}$ magnitude TT star.

¹¹ Performance decrease driven primarily by simplification to laser asterism and reduction in laser power.

¹² KAON 461, Table 1 for NGS 'bright star' performance.

¹³ KAON 461, Appendix 1 for NGS mode with 8th magnitude TT star. Note, NGWFC should have similar performance, because the Keck 1 LGS upgrade will not affect NGS science performance.

requirements for certain science cases indirectly increased the difficulty of meeting the requirements in Table 1. Offsetting this, a calculation error was identified and corrected (§5.7), improving NGAO tip-tilt performance for high sky fraction science cases.

During the PD phase, these budgets were collated into three key spreadsheet documents:

- KAON 721, "Wavefront Error Budget Tool"
 - o Containing Wavefront Error and Ensquared Energy Budgets
- KAON 722, "NGAO High-Contrast Error Budget Tool"
- KAON 723, "Performance Flowdown Budgets"
 - Containing transmission and background budgets, astrometric precision budget, observing efficiency and uptime budgets, and numerous supporting flow-down budgets such as non-common-path tip/tilt budget and non-correctable wavefront error budgets.

3.3 Wavefront Error Requirements Summary

The highest-level performance requirements for NGAO are documented in the Systems Requirements section of the NGAO Requirements Contour Database (see Appendix A), with the key requirement for wavefront and ensquared energy documented in SR-20, summarized in Table 2, and SR-21, which states

"The NGAO system shall produce a point spread function of a point source object with an ensquared energy of greater than or equal to 50% with a size of 70 mas as measured at the center of the science instrument focal plane for targets with a zenith angle of less than 5 degrees."

NGAO Key Science Case	High-order Wavefront Error (nm, RMS)	Tip-tilt Error (mas, RMS)	Effective Total RMS Wavefront Error (nm)	Science Pass- band	Strehl Ratio	Ensquared Energy within a 70 mas spaxel	Single- Integration Time (sec)
Galaxy Assembly	163	4.9	185	К	76%	74	1800
Nearby AGN's	163	4.7	181	Z	19%	26 w/in 34 mas	900
Galactic Center	190	2.2	193	Н	58%	59	10
Exoplanets	162	3.8	174	Н	64%	68	300
Minor Planets	164	4.7	181	К	77%	25	120
lo	115	2.1	117	K	89%	83	10

Table 2. High-level NGAO Wavefront Error Performance Requirements Summary from SR-20. High-order (HO) wavefront errors are errors with spatial frequencies higher than the tip-tilt (TT) error modes. The Effective Wavefront Error is the error that provides the same Strehl, through the Marechal approximation, as the produce of HO and TT Strehl ratios. EnsqE is within a 70 x 70 mas spaxel, except in the case of the Nearby AGN's science case, where the Z-band EnsqE estimate is given for a 34 x 34 mas spaxel.

Detailed description of the error budgets that support SR-20, and their basis, constitutes the majority of this report. The KAON 721 wavefront error budget tool is described in §16, an example detailed budget for the Galaxy Assembly case is provided in §6, and summary detailed budgets for the full suite of NGAO science cases are provided in Appendix A.

3.4 High-Contrast Requirements Summary

The highest-level image contrast requirement for NGAO is captured in SR-98, which states

"The NGAO system shall be able to detect point sources with brightness contrast as follows:

Separation	ΔΗ	ΔJ
0.1"		8.5 (goal = 11)
0.2"	10	11
1.0"	13	

Table 3. High-level NGAO Contrast Requirements from SR-98.

SR-98 is traceable to KAON 455, Science Case Requirements Document, for two classes of observation: the ΔH requirements from companions to nearby (20-30 pc) stars and the ΔJ requirements from Jupiter analogues around T Tauri stars.

High-contrast performance estimates are maintained in a separate configuration controlled spreadsheet, KAON 722. Based upon a spreadsheet originally developed by B. Macintosh of LLNL in support of the GPI adaptive optics system, KAON 722 uses a spatio-temporal power spectrum model for each of several key AO system aberrations to evaluate the residual speckle and photon noise in the cleared-out 'dark hole' region surrounding an idealized AO coronagraphic PSF.

Due to the specialized nature of high-contrast observations, and the relative lack of detailed high-contrast performance simulations utilizing LGS (not to mention tomographic LGS) wavefront sensing, there are relatively few direct performance flow-down requirements. Most importantly, NGAO has made a design decision to sample and correct the telescope pupil with N=60 subapertures spanning the 10.949 meter Keck Telescope maximum diameter, a decision driven not by our usual WFE optimization process (§5.3), but rather KAON 722 considerations. Specifically, we have maintained N=60 in order to provide NGAO high spatial frequency control for speckle clearing over a large AO working angle. Strictly speaking, we have found NGAO WFE performance quite weakly dependent upon the exact choice of N=60 ranging between N=48 and N=64, when bandwidth error (frame rate) reoptimization is performed. Compared to our SDR choice of N=64, we subsequently revised our sampling baseline to N=60 in order to manage known pupil nutation seen at the Keck Telescope Nasmyth platform.

During the NGAO DD phase, additional high-contrast modeling will be performed as part of the further refinement of the DAVINCI coronagraph design.

3.5 Astrometric Precision Requirements Summary

The highest-level astrometric precision requirement for NGAO is captured in SR-47, which states

"NGAO shall achieve an astrometric precision of 100 microarcseconds for observations taken with 120 seconds of each other and 250 microarcseconds for observations taken within 30 days."

KAON 480 describes the key considerations for meeting the NGAO astrometric precision requirements, in both sparse field and crowded field science scenarios. During the PD phase, we expanded and organized an astrometric error budget and incorporated this into KAON 723, "Performance Flow-down Budgets". Because of the research nature of understanding the root causes and limitations of astrometric variability of the current Keck II LGS AO system, it is difficult to make quantitative assessment of all factors potentially affecting NGAO astrometric precision. Still, using KAON 723 as a guide, we know that astrometric precision will be improved as wavefront error is reduced, particularly for crowded field science, such as the Galactic Center, where source confusion is thought to be among the major error sources.

One of the flow-down requirements from the astrometric precision budget (already implemented at Mauna Kea) is the installation of an active $C_n^2(h,t)$ monitor, which will provide turbulence structure and anisoplanatism information in support of post-observing data analyses, including anisoplanatic PSF estimation¹⁴.

4 NGAO Science Cases

Science Case parameters for NGAO have been updated by Max and McGrath during the NGAO preliminary design phase (XXX Need KAON reference for this). The updated parameters are repeated here for convenience in Table 4.

			1					•				•
				Require	Galactic	1				NGAO	Error Budget Case	
	Zenith			d sky	latitude,	1		Max Single		Key	Name (if different	
	Angle		NGS	coverag	b	Science	Evaluation	Exposure	LGS/NG	Science	then Science Case	Applicable to
Science Case Name	(Deg)	Guide stars	color	e (%)	(deg)	Filter	Filter	Time (Sec)	S	Case	Name)	NGAO (Yes/No)
Key Science Drivers												
Galaxy Assembly, e.g. Extended Groth S	30	Field Stars	М	30	≥60	Z, J, H, K	J, K	1800	LGS	Υ		Key Science Drive
Nearby AGNs	30	Field Stars	M	30	≤60	Z, J, K	Z	900	LGS	Υ		Key Science Drive
		`	,					<10 (image)				
Galactic Center	50	IRS 7, 9, 12N	N/A	N/A	N/A	H, K	K	900 (spectra)	LGS	Υ		Key Science Drive
Exo-planets	30	Field Stars	М	30	≤30	J, H	Н	300	LGS	Υ		Key Science Drive
Minor Planets	30	Field Stars	М	30	≤60	Z	Z	120	LGS	Υ		Key Science Drive
Science Drivers												
		Field Stars,			•							
		possibly the										
QSO Host Galaxies	30	science object	M/ A?	30	≤60	Z, J, H, K	К	900	LGS			Science Driver
Gravitational Lensing	30	Field Stars	М	30	≥60	I, Z, J, H, k	J, K	1800?	LGS			Science Driver
Astrometry Science	30	Field Stars	М	30	≤60	Н, К	Н	30 ?	LGS			Science Driver
Transients	30	Field Stars	М	30	40	Z, J, H, K	Z	900	LGS	N		Science Driver
Resolved Stellar Populations	50?	Field Stars	M?	30	?	I, K	I	300?	LGS			Science Driver
Debris Disks and Young Stellar Objects	30	Field Stars	М	30	≤30	I, Z, J, H	I	300	LGS			Science Driver
Size, Shape, and Composition of Minor F	30	Field Stars	М	30	≤60	I, Z, J	I	120	LGS			Science Driver
		Satellites (non-										
Gas Giant Planets		sidereal)	G	N/A	N/A	J, H, K	К	2?	NGS?			Science Driver
		Satellites (non-										
Ice Giant Planets		sidereal)	G	N/A	N/A	J, H, K	н	2?	LGS			Science Driver

Table 4. Science Cases Parameters for NGAO PD phase.

_

¹⁴ Britton, M. C., "Analysis of crowded field adaptive optics image data," in Advances in Adaptive Optics II. Edited by Ellerbroek, Brent L.; Bonaccini Calia, Domenico. Proc. SPIE, Volume 6272, July 2006.

These input parameters represent the observing scenario details developed via the process of Figure 1 and are the parameters that will be used in the summary evaluation of NGAO performance for all science cases in §8.

5 KAON 721, "Wavefront Error Budget Tool"

5.1 Introduction

NGAO performance The primary tool for the development and maintenance of the NGAO WFE budgets is a sophisticated Microsoft Excel spreadsheet (KAON 721) developed at Caltech by R. Dekany and collaborators over the past 10 years and significantly expanded for NGAO. It has been extensively validated against engineering error budgets maintained by Wizinowich, Neyman, and van Dam (§5.7.1), validated with detailed wave-optics Monte Carlo simulations (e.g. Arroyo, LAOS), and vetted against error budgets developed for TMT NFIRAOS (§5.7.2). It has also been anchored to observed on-sky performance of operational AO systems at Keck and Palomar Observatories.

KAON 721 supports the rapid evaluation of wavefront error budgets applicable to different AO systems / modes (e.g. Keck II NGS / LGS or NGAO NGS / LGS), different observing scenarios, typically designed to correspond to NGAO science cases, and different science instrument options (e.g. OSIRIS, DAVINCI).

The selection of WFS camera frame rates and off-axis NGS brightnesses and distances are typically optimized parameters that are found subject to constraints of necessary sky coverage fraction or guide star brightness, in the case of a known specific science target. Thus, each error budget for NGAO corresponding to each key science case, assumes operation at a slightly different frame rate¹⁵.

Through a series of configuration worksheets, KAON 721 provides a detailed description of the parameters necessary to accurately model AO system performance:

- AO system architectures and design choices
- Atmospheric turbulence models
- Telescope parameters and as-built optical performance metrics
- WFS detector properties, such as quantum efficiency, dark current, and read noise
- Numerous adaptive optics error budget terms, specific to any of several distinct AO system architectures (e.g. SCAO, MCAO, MOAO) for both NGS and LGS guide star modes
- Atmospheric dispersion
- Calibration and systematic error terms, such as thermally induced non-common-path flexure
- Several astronomical stellar density models for the evaluation of AO sky coverage

The assumptions and impact of several of these quantities are described here in subsequent sections.

KAON 721 has been successfully applied for over 10 years of design and on-sky validation of AO system performance at Palomar Mountain, and is considered proprietary to Caltech Optical Observatories,

¹⁵ A future revision to KAON 721 may support definable, selectable WFS frame rates, but this is not currently supported.

available for distribution within NGAO. Within the context of the NGAO project, specific validation activities for KAON 721 are described in §5.7.

In the following sections, we briefly describe the input parameters and underlying error term calculations and allocations that constitute the NGAO wavefront error performance budget within KAON 721.

5.2 "Input Summary" Sheet

The large majority of architectural and observational parameters used to define each system evaluation are captured on a single 'Input Summary' worksheet of the KAON 721 workbook. Certain of these parameters represent NGAO architecture choices, while others are design choices made within individual NGAO subsystems. Collectively, they begin the flowdown of the highest-level SR-20 performance requirements, a process continued in further detail in KAON 723.

During the DD phase, we intend to revise this sheet to even more clearly capture more of the parameters needed to describe AO system architecture, and maintain the configurations of each of the NGAO science cases, should they evolve.

Tolescope	Parameter Name Declination Dec	8.0 G 0 0.00050 0.0050 0.00050 CCID74 3E+09 NGS	deg mm/s mm/s mm/s mm/s mm/s mm/s mm/s mm/	3E+00	Galaxy Assembly 30 LGS	Nearby AGN 30 LGS	50		Exo-planets 30 LGS	30	Io 30 NGS 5.0 G	Driver QSO Host Galaxies 30 LGS	Gravitational Lensing 30 LGS	Astrometry Science 30 LGS			Debris Disks and YSOs	Gas Giant Planets 30 LGS	
Tolescope	Parameter Name Declination Dec	Parameter Value 30.0 Maura Kea Ridge 6.0 Maura Kea Ridge 6.0 6.0 6.0 6.0 6.0 6.0 6.0 6.0	deg mm/s mm/s mm/s mm/s mm/s mm/s mm/s mm/		Assembly 300	30	50	Spectra 50	30	Planets 30	30 NGS 5.0	Galaxies 30	Lensing 30	Science 30	30	Stellar Populations	and YSOs	Giant Planets 30	Giant Planets 30
Atm E C C C C C C C C C C C C C C C C C C	Declination Zenth Angle Diction Model of a Zenth Angle Diction Model of a Zenth Duter Scale Guide Star Spectral Type Guide Star Spectral Type Guide Star Spectral Type Guide Star Spectral Type Winn LOS Sudopa Across Horney Star Spectral Type Winn LOS Sudopa Across Horney Star Spectral Type Horney Star Star Spectral Type Horney Horney Horney Star Star Star Spectral Type Horney	30.0 Maura Nea Ridge (1.5 Maur	m (MSGLGS) (LGS						NGS 5.0								NGS
C C V V V V V V V V V V V V V V V V V V	Cin2(i) Model of a Zenith Wind speed of a Zenith Wind State of a Zenith Wind State of a Zenith Wind State of a Zenith of a Zenit	Maura Ken Ridge 0.100 0.100 0.100 0.100 0.100 0.000 0.0000 0.00000 0.00000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.00000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.00000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.00000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.000000	m (MSGLGS) (LGS						NGS 5.0								NGS
R	O at Zenith Wind speed Julier Scale Julier S	0.160 9.55 8.0 8.0 8.0 8.0 9.5 9.5 9.5 9.5 9.5 9.5 9.5 9.5 9.5 9.5	m/s m/s (NGS-LGS) m/V Sees time(s) seconds seconds seconds seconds (Measured/Theoretical) arcsec			LGS	LGS	LGS	LGS	LGS	5.0	LGS	LGS	LGS	LGS	LGS	LGS	LGS	
HO Flux G HO Flux G H H H H H H H H H H H H H H H H H H	Outer Scale Guide Star Spectral Type Guide Star Spectral Type Guide Star Spectral Type Guide Star Spectral Type Winn LGS Sudges Across How Star Spectral Type Winn LGS Sudges Across How Star Star Spectral Type How Star Compare Latency How Mark LGS Enderson to How Star Compare Latency How Mark LGS Enderson to How Star Compare Latency How Mark LGS Enderson to How Star Compare Latency How Mark LGS Enderson to How Star Compare Latency How Mark LGS Enderson to How Star Compare Latency How Mark LGS Enderson to How Star Compare Latency How Mark LGS Latency How Star Compare L	90 NOSS 8.0 G G G G G G G G G G G G G G G G G G G	m (MSS/LS) mV sec (MSS/LS) mV			LGS	LGS	LGS	LGS	LGS	5.0	LGS	LGS	LGS	LGS	LGS	LGS	LGS	
G G G G G G G G G G G G G G G G G G G	Guide Star Brightness O-WYE'S NGS Spectral Type Warn LOS Subage Across Warn LOS Subage Across Warn LOS Subage Across Warn LOS Subage Across Holl Star Los Warn Holl Star	8.0 G 0 0.00050 0.00050 0.00050 0.00050 0.00050 0.00050 0.00050 NGS Measured 1.00 1.00 0.00 0.00 0.00 0.00 0.00 0.0	mV sec frame time(s) seconds seconds seconds atoms/cm²2 Watts (kleasured/Theoretical) arcsec			LGS	LGS	LGS	LGS	LGS	5.0	LGS	LGS	LGS	LGS	LGS	LGS	LGS	
H	HOWER NASS Spectral Type Num LGS Studges Across Num NGS Sudges Num NGS Sudge	G 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	sec frame time(s) seconds seconds seconds atoms/cm/2 Watts (Measured/Theoretical) arcsec arcsec		LGS						G								G
Na Na Na Na Na Na Na Na	Num NGS Subage Across Vann NGS Subage Across FO WFS COOT Read Him FOR FTC Compare Latency HOWE'S Detector As Column Deraily Pulse Format Laser Power House Format Laser	0.00050 0.500 0.00050 0.00050 CCIID74 3E+09 NGS NGS Measured 1.00 0.00 0.00 0.00 0.00 0.00 0.00 0.0	frame time(s) seconds seconds seconds atoms/cm*2 Watts (Measured/Theoretical) arcsec arcsec		LGS														
H H H H H H H H H H H H H H H H H H H	+10 Integration time +10 Integration time +10 IRTC Compute Latency +10	0.50 0.00050 0.00050 0.00050 CCID74 8E+09 NGS NSS Measured 1.00 4 1.6 0 3.9 0.00 0.0 NO	frame time(s) seconds seconds seconds atoms/cm*2 Watts (Measured/Theoretical) arcsec arcsec		LGS														
H	HO RTC Compute Latency Phis RTC Compute Latency HOWES Detector 140 A Column Dereity 140 A Column	0.00050 0.00500 0.00500 CCID74 SE+090 NGS NGS NGS 4 1.00 4 1.6 0.3 9 0.000 0.0 NO 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0	seconds seconds seconds seconds atoms/cm*2 Watts (Measured/Theoretical) arcsec arcsec		LGS														
LGS Flux N P L HO Cent N P R I L L C R FA Tomo N L L S S Na H V	HOWE'S Detector As Column Dernity Pulse Format Jase Power Jase	CCID74 3E+09 NGS NGS NGS 4 1.00 4 1.6 0 3.9 0.00 0.0 NO 0.02 55 0.25	atoms/cm*2 Watts (Measured/Theoretical) arcsec arcsec		LGS														
LGS Flux N P P P P P P P P P P P P P P P P P P	Na Column Density Publice Format Laser Power Heaturn Calculation Basis Laser-Annu-LLT Transmission Laser-Annu-LLT Transmission Laser-Annu-LLT Transmission Problem Column Research Rese	3E+09 NGS NGS Measured 1.00 4 1.6 0 3.9 0.00 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0	Watts (Measured/Theoretical) arcsec arcsec		LGS														
L R R L L L L L L L L L L L L L L L L L	Lase Power Return Calculation Basis Lase-ethnut-LLT transmission Num Pixels per Subap Across Pixel Bro's Labap Across Perfect Light's Cord Perfect Light's Acro Perfect Light's Acro Perfect Light's Acro Perfect Light's Acro Perfect Light's Power LLT Off-axis Projection Distance LLT Off-axis Proj	NGS Measured 1.00 4 1.6 0 0.00 0.0 0.0 0.0 0.0 0.0 0.25	(Measured/Theoretical) arcsec arcsec	Measured	LGS														
HO Cent N P R I I A L U C C A FA Tomo N L L L S S NNa H V	Lase-ethnu-LLT transmission Num Pixels per Subap Across Pixel IF 20' Pixel IF 20' Pixel IF 20' Parage Galon' Parage Galon' Particle Substitution of Carlotte Perfect Lightin A 07' Abberrations in Uplank Beam LLT Off-axis Projection Distance LLT Off-axis Projection Distance LLT Off-axis Projection Distance Large Mausion Charles Marchael Consultation Charles Marchael Consultation Charles	1.00 4 1.6 0 3.9 0.00 0.0 0.0 NO 0.25 0.25	arcsec	Measured	LGS														
HO Cent N P R R I I P A L U C A FA Tomo N L L L S S Na H V	Num Pixels per Subap Across Pixel FoV Range Galing? Intrinsie HOWPS GS diameter Perfect Uplink AO? Abbrations in Uplink Beam LIT Off-axis Projection Distance Lee Max LGS Englision in Calculation? District Abertations ADC in HOWPS? AUTO Laser Beacons LGS Beacon Height show Telescope LGS Asteriam Radius LGS Asteriam Radius LGS Asteriam Radius	4 1.6 0 3.9 0.00 0.0 NO 0.25 0.25	arcsec		LGS														
R III III III III III III III III III I	Range Galing? Intrinsie HOWPS GS dameeter Perfect Uplink AO? Abberations in Uplink Beam LLT Off-axis Projection Distance LLT Off-axis Projection Distance LLT Off-axis Projection Distance Late Max LGS Elempation in Calculation? Downlink Abberations Downlink Abberations Downlink Abberations Downlink D	0 3.9 0.00 0.0 0.0 NO 0.25	arcsec		LGS														
P A A L U D C C A A FA Tomo N L L L S S Na H V	Intrinsic HOWFS GS diameter Perfect Uplink AO Perfect Uplink AO Pe	0.00 0.0 0.0 NO 0.25 0.25			LGS														
A L U U C C A A FA Tomo N L L S S Na H V	Abermations in Uplink Beam LLT Off-axis in Projection Distance Use Max LGS Elongation in Calculation? Downlink Abermations Charge Diffusion ADC in HOWFS? Number of Laser Beacons LGS Beacon Height above Telescope LGS Asterism Radius Single Laser Beakproj FA Reduction Factor	0.0 0.0 NO 0.25 0.25	arcsec m			LGS	LGS	LGS	LGS	LGS	1.1	LGS	LGS	LGS	LGS	LGS	LGS	LGS	3.9
L U D C A FA Tomo N L L S Na H V	LIT Offaxis Projection Distance Lise Max LGS Etongation in Calculation? Downlink Aberrations Dhorage Diffusion ADC in HOWFS? Number of Laser Beacons LGS Beacon Height above Telescope LGS Asterism Radius Single Laser Backproj FA Reduction Factor	0.0 NO 0.25 0.25	m																
FA Tomo N L L S Na H V	Downlink Aberrations Charge Diffusion ADC in HOWFS? Number of Laser Beacons LGS Beacon Height above Telescope LGS Asterism Radius Single Laser Backproj FA Reduction Factor	0.25 0.25																	
FA Tomo N L L S Na H V	ADC in HOWFS? Number of Laser Beacons LGS Beacon Height above Telescope LGS Asterism Radius Single Laser Backproj FA Reduction Factor	0.25	arcsec	NO															
FA Tomo N L L S Na H V	Number of Laser Beacons LGS Beacon Height above Telescope LGS Asterism Radius Single Laser Backproj FA Reduction Factor		pixels																
L S Na H V	LGS Asterism Radius Single Laser Backproj FA Reduction Factor	0																	
Na H V	Single Laser Backproj FA Reduction Factor	90	km arcmin																
		1.0																	
Fit P	Vertical Velocity of Na Layer Physical Actuator Pitch	0.0035		30.0															
	Use Anti-aliasing in HOWFS? Aliasing Reduction Factor	YES 0.67		0.67															
Stroke N	Number of Woofer Actuators Across Pupil	20		0.07															
N V	Number of Tweeter Actuators Across Pupil Woofer Peak-to-Valley Stroke	64	microns																
T	Tweeter Peak-to-Valley Stroke		microns																
T	Woofer Interactuator Stroke Tweeter Interactuator Stroke	1.2 0.5																	
V	Woofer Conjugate Height Tweeter Conjugate Height	0.0	meters meters																
S	Static Surface Errors to be Corrected	1.0	microns																
Go-To S Dig N	Science Mode Number of Controller Bits	SCAO 16	(SCAO/MOAO/MCAO)																
TT Flux T	TT Guide Star Brightness	8.0	mV				12.2	12.2	18.3		5.0						16.0	5.0	
T	TT NGS Spectral Type Subaperture Shape	G circular	(circular/square)	circular	М	М	IRS7	IRS7	М	М	G	М	М	М	М	М	М	G	G
	Num TT Sensors Used for TT	0																	
N	Num TTFA Sensors Used for TT Num 3x3 Sensors Used for TT	0																	
N	Num HOWFS Used for TT TT Integration Time	0.0005	000																
T	TT Compensation Mode	0	(SCAO/MOAO/MCAO/MOA	O Point and Sho	ot, Indep PnS)														
	TT Detector TT Sensor Type	CCID74 NGS	(Pyramid/SH)																
T	TT Star Sharpened by AO?	NO	(i yiaiiia ori)																
A	Assume Fermenia TT Sharpening? ADC in TT sensor?	NO NGS		NO															
N	Num TT Pixels Across Subap	4																	
T	TT Binning Factor TT Pixel IFoV		arcsec																
	Intrinsic TT GS diameter TWFS Guide Star Brightness	3.9	arcsec mV				12.2	12.2	18.3		1.1 5.0						16.0	5.0	3.9 8.0
T	TWFS NGS Spectral Type	G			М	М			10.3	М	G	М	К	М	M	М		G	
	Num TWFS Subaps Across Num TWFS Pixels Across Subap	NGS NGS																	
T	TWFS Integration Time	2.0000	sec																
T	TWFS Compensation Mode TWFS Pixel IFoV	SCAO 1.60	(SCAO/MOAO/MCAO) arcsec																
	TWFS Detector Kappa	NGS 1.0																	
H	HO Servo Decimation Factor	20																	
T	TT Servo Decimation Factor Telescope Input TT Reduction Factor	20 0.50																	
L	LGS Focus Sensor	N/A NO	(TWFS/TT)	NO.															
	Optimize LGS Off-pointing HO GS to Target for Sci Aniso WFE	1.00	arcsec	NO	1.0	1.0	1.0	2.0	1.0	0.0	0.5	1.0	5.0	5.0	1.0	5.0	1.0	5.0	1.0
н	HO GS to TT GS for TT Aniso WFE	-1.00	arcsec			1.0	5.6	5.6	0.0		0.5		2.0	2.0	7.0	3.0	0.0	30.0	1.0
	TT GS to Target (for TT Anisoplanatism) TWFS GS to Target (for Truth Anisoplanatism	0.00	arcsec				5.6 5.6	5.6 5.6	0.0		0.5						0.0	30.0 30.0	1.0
CA C	CA Rejection Factor	NGS	arcsec				5.6	5.6	0.0		0.5						0.0	30.0	1:0
Atm Dispersion S	Science ADC? Science Disperson Correction Factor	YES 20		20															
Cal In	nstrument	DAVINCI		20															
L C	Uncorrectable AO System Aberrations Dynamic WFS Zero-point Calibration Error	25 20	nm nm																
L	Leaky Integrator Zero-point Calibration Error	10	nm																
0	DM-to-lenslet Misregistration Errors DM-to-lenslet Scale Errors	10	nm nm																
Margins H	High Order Wavefront Error Margin	45 2.0	nm mas																
Sky Coverage T	TT Star Density Model	Spagna		Spagna															
R	Required Sky Coverage Fraction TWFS Star Density Model	N/A Bachall		Bachall	30%	30%	N/A	N/A	30%	30%	NGS	N/A	30%	30%	30%	30%	30%	N/A	N/A
R	Required TWFS Sky Coverage Fraction	N/A		Duvidi															
Science Filter P	Galactic Latitude, b Primary Science Filter	N/A H	deg		60 K	60 Z	0 H		30 H	60 Z	N/A Z	60 H	60 H	60 H	40 Z		30	N/A K	N/A H
N	Max Science Exposure Time	2	sec		1800	900		900	300	120	10	900	1800	30	900			2	2
Worksheet P		Current	Units		Galaxy	Nearby AGN	Gal Cen	Gal Cen	Exo-planets	Minor			Gravitational	Astrometry	Transients	Resolved	Debris	Gas	Ice
		Parameter Value			Assembly			Spectra		Planets		Galaxies	Lensing	Science		Stellar Populations	Disks	Giant Planets	Giant
																- opulations	YSOs	anets	anecs

Table 5. KAON 721 "Input Summary" worksheet, configured for NGAO LGS mode observing and the Galaxy Assembly key science case. Red fields indicate entries that may be affected by optimizations. Red typeface indicates observing scenarios needing NGAO NGS mode.

The terms in Table 5 are largely self-explanatory, although their quantitative implementation requires reference to KAON 721 itself. All the same, a few items are worthy of additional explanation here:

• **HO Flux, Number of Subapertures Across**: NGAO has high-order wavefront sensors designed to sample the telescope pupil with ~60 subapertures across the 10.949 m maximum diameter.

Our WFS's, however, are designed for 63 x 63 subaperture format (e.g. oversizing the pupil somewhat) to handle known pupil nutation in the Keck telescopes. See Keck Drawing 1410-CM0010 for more detail.

- **HO Flux, HO WFS CCD Read Time** is currently given as a fraction of the HO WFS frame rate, which is typically an optimization variable. In the future, this will be replaced with an amplifier dwell time or equivalent parameter to specify the detector read time.
- LGS Flux, Na Column Density of 3 x 10⁹ atoms/cm² is below median density (approximately 25th percentile). See Figure XXX for a trade study of performance vs. sodium density.
- TT Flux, TT Compensation Mode is a complex choice that supports traditional single-conjugate
 AO correction, MCAO, single-LGS MOAO correction, and multiple patrolling LGS (aka 'Point and
 Shoot') architectures. Changes to this parameter must be carefully understood by the KAON
 721 user.
- Atm Dispersion, Science Dispersion Corrector Factor uses a crude multiplicative (divisive, actually) factor to estimate the residual performance, if a science ADC is used. In the future, KAON 721 will allow for definition of more realistic, design-informed residual dispersion.
- Margins (e.g. performance margins) are held apart from physical error terms and constitute the difference between use of KAON 721 as an error budget (including margins) and as a performance prediction or system diagnostic tool (assuming margins are not invoked.)

[XXX – more to do; need feedback on the least obvious of the Input Summary entries].

5.3 Optimization ("Optim") Sheet

Error budgets are summarized on the 'Optim' worksheet, as this is location of the optimization parameters. (Optim is commonly used for the generation of trade study results, as well.) Separate error budgets are maintained for the science path, the sharpening of field TT stars, and for the wavefront error residual sensed by the TWFS (if applicable). For patrolling LGS TT sharpening systems, the camera frame rates of corresponding HO LGS WFS's are separately optimized. Additional description of this tool is provided in Appendix C (XXX verify).

5.4 Encircled / Ensquared Energy ("EE") Sheet

KAON 721 employs a multi-halo model to estimate the encircled or ensquared energy in the NGAO PSF. The intent is to approximately model the effect of residual wavefront errors of different spatial frequency. For example, residual tip-tilt errors are treated as a convolution of the diffraction-limited PSF with residual TT errors, while high-order WFS measurement error results in light scattered to high spatial frequencies as it manifests as random noise on the HODM surface. Five different width Gaussians contribute to the PSF model:

- Diffraction-limited, convolved with TT errors
- ½x the seeing-limited width (containing low spatial frequency errors, such as focus errors due to sodium height variations)
- A variable-width PSF for focal anisoplanatism (for which the width of the component is a function of the focal anisoplanatism coherence parameter, d₀)

- 1x the seeing-limited width (containing most atmospheric residual errors)
- 2x the seeing-limited width (containing measurement error, scintillation, and uncorrectable telescope, AO, and instrument errors.)

The power in each component is calculated assuming 1) the DL component has the fraction of energy represented by the Strehl ratio (at the observing wavelength), 2) the remaining fraction of energy (1-SR) is allocated into each of the four remaining components based on the relative power of the corresponding error terms (e.g. allocated by wavefront variance). A check is made to ensure the sum of all PSF components is appropriately normalized.

KAON 721 also provides seeing-limited encircled / ensquared calculations for comparison purposes.

5.5 Wavefront Error Budget Terms

5.5.1 High-order Wavefront Errors

5.5.1.1 Atmospheric Fitting Error

We use the standard model for fitting error,

$$\sigma_{Fitting} = \left(\frac{500}{2\pi}\right) \sqrt{\alpha_F \left(\frac{\Delta x}{r_0}\right)^{\frac{5}{3}}} \text{ nm}$$

Where a_F = 0.28 assuming a continuous facesheet, pyramidal DM influence function.

5.5.1.2 Bandwidth Error

During the PD phase, we have implemented the bandwidth servo error model described in detail in KAON 710, which is based upon a Fourier domain analysis of the 'open-loop' go-to control law in a discrete time system. From Equation 13 of KAON 710,

$$\sigma_{Bandwidth} = \left(\frac{500}{2\pi}\right) \quad \sqrt{\zeta[\alpha] \left(\frac{vT}{r_0}\right)^{\frac{5}{3}}} \text{ nm}$$

Where $\zeta[\alpha]$ is the open-loop normalized variance numerically derived to be,

$$\zeta[\alpha] = 5.57 \ \alpha^2 + 25.125 \ \alpha + 11.38$$

where $\alpha = \tau_c/T$ is the delay parameter describing the compute delay t_c in units of frame time T, and v = turbulence-weighted wind velocity and T the WFS frame time.

5.5.1.3 High-order Measurement Error

High-order wavefront measurement error is perhaps the most complicated of the calculations supported in KAON 721. For our purpose here, it will suffice to describe the error as,

$$\sigma_{Measurement} = \left(\frac{500}{2\pi}\right) E_{P} \frac{\pi}{8 \text{ SNR}} \sqrt{\left(\frac{3}{2} FWHM_subap\right)^{2} + \theta^{2}} \text{ nm}$$

Where $E_p = 0.1902 + 0.1067*In(N^1)$ based on Hardy, Table 8.2, pg 276 (see also Eqn 9.58, pg 342) is the reconstructor error propagator between centroid error and error of the wavefront reconstructed in the pupil plane for each measurement. SNR is the signal-to-noise ratio of the subaperture detection and includes the following physical effects:

- Guide star flux (sodium LGS or NGS)
 - Based upon measured LGS return data reported from SOR as extrapolated to Mauna Kea's latitude, magnetic field direction, measured (Hakeakala) seasonal sodium abundance, LGS distance, atmospheric extinction
 - O Thus, we assume 100 photons/cm²/sec/W coupling efficiency, where W are Watts of laser power delivered to the mesosphere and photons are measured above the Earth's atmosphere on the downlink, and a sodium column density of 3 x 10⁹ atoms/cm².
- NGS stellar spectral type, if applicable
- WFS exposure time
 - o Typically assuming 100% shutter efficiency
- System transmission for each WFS path, including any band-defining filters
 - Using detailed coating models, including coating degradation and dirt (scatter) losses for each surface, depending on its local atmospheric environment
 - Including transmission contingency of 3% held at the system level (to be allocated should acceptance testing of coating data miss the mark, particularly for long lead items).
- Detector QE, read noise, dark current
 - Based on measured data of noise vs. frame (readout) rate for each type of WFS CCD camera under consideration
 - This is typically 2.2 e- read noise for the CCID74 when operating at 1,000 fps
- Fratricide noise
 - Implemented in a pupil-average sense of contributing additional 'background' noise, calculated from Rayleigh scatter lidar equations. In this case the statistics depend both on Poisson noise and assumptions about the fluctuations in Rayleigh background and the cadence of LGS WFS de-tuning to re-measure the WFS background.
- Sky background in the observing band of the sensor
 - Based on the physical instantaneous field of view (IFoV) of the WFS pixel or binned super-pixel, whichever is appropriate.
- Phase of the moon, as a contributor to scattered light
- The effective servo loop gain, which considers the contribution from photons collected during a -3db time, not just that collected during a single WFS exposure time.

And FWHM_{subap} is the full-width-at-half-maximum of the subaperture WFS image, which is calculated taking into account the following physics, most of which generate specific functional requirements through the performance budget flowdown:

- Subaperture diffraction in the WFS observing band
- NGS size
 - o Intrinsic size of the guide star
 - o Tip-tilt removed atmospheric seeing on the downlink
 - o Atmospheric dispersion across the WFS band
 - o Any dispersion correction
- Or, LGS size
 - o Laser beam image quality
 - o Beam transfer optics quality
 - o Tip-tilt removed uplink atmospheric aberrations over the projector aperture
 - Any higher-order uplink pre-compensation
 - o Off-axis LGS perspective elongation
 - o Tip-tilt removed atmospheric seeing on the downlink
 - WFS detector charge diffusion (including any binning effects)
- Uncorrectable aberrations in the telescope and AO system

Built upon these principles, we typically estimate the FWHM of the LGS spot to be 1.27 arcsec (average over the telescope aperture).

Furthermore, KAON 721 calculates measurement noise independently in LGS mode for both the fixed laser asterism and the patrolling laser asterism, which are allowed to run at different frame rates in order to optimize system performance.

5.5.1.4 LGS Tomography Error

KAON 721 captures in a parametric fashion the fundamental results of detailed Monte Carlo wavefront optics propagation modeling conducted with LAOS and two independent codes developed by R. Flicker and D. Gavel. The results of some of these tomographic analyses are documented in KAON 429, "LGS asterism geometry and size" and KAON 492, "NGAO null-mode and quadratic mode tomography error". Based on these studies, we found the key determinant to estimating the null-mode corrected tomography error to be the areal density of LGS beacons on the sky. Secondary to this, the specific distribution of LGS on sky had relatively minor impact, resulting in small azimuthal field-dependent errors over our small NGAO FoV.

A detailed validation comparison of our different codes is described in KAON 475, "Tomography Codes Comparison and Validation for NGAO" as well as indirectly within KAON 629, "Error budget comparison with NFIRAOS".

Our choice of LGS fixed asterism (a triangle on 10 arcsec radius plus a central LGS), results in a predicted, null-mode corrected tomography error of 37 nm RMS. We achieve this assuming null-mode correction

based upon the use of 2 tip-tilt and 1 tip-tilt-focus-astigmatism NGS, that are themselves sharpened by the patrolling LGS + LO WFS AO subsystems, as described in KAON 492.

Because these wave-optics-based performance estimates were used primarily in the design process of the fixed LGS asterism, we intend to conduct further simulation-based analysis of our selected asterism (for e.g. more robust understanding of zenith angle dependency) in the DD phase.

5.5.1.5 Multispectral Error

The wavefront error that arises from wavefront sensing in a different band than the science band is known as multispectral error. It arises from differential atmospheric refraction of the two beams, resulting in the sensor light following a slightly displaced path through the Earth's atmosphere. A quantitative model of this error as a function of zenith angle and wavelength difference, provided by Hardy (Ch. 9.3.4, pg 325) and is coded into KAON 721.

5.5.1.6 Uncorrectable Static Telescope Aberrations

Flicker and Neyman reported on the ability of NGAO to correct for measured Keck telescope segment map aberrations in KAONs 469, "Effect of Keck Segment Figure Errors on Keck AO Performance" and 482, "Keck Telescope Wavefront Error Trade Study". That model is encoded in KAON 721, and predicts a residual of 42 nm RMS, one of the largest error terms in the budget. Static errors in the Keck primary tend to hold up our choice of actuator density (N=60 across the pupil) to higher density than we might otherwise choose based on atmospheric fitting error (§5.5.1.1) alone.

5.5.1.7 Uncorrectable Dynamic Telescope Aberrations

Dynamically changing Keck telescope aberrations (e.g. segment vibrations, excluding a global pointing jitter handled in §5.5.2.2) are allocated 25 nm RMS in the NGAO error budget. This is a rather uncertain number, however, and is based upon private communications with the primary mirror phasing team (Chanan and Troy). More detailed analysis of the dynamical ability of NGAO to reject mirror segment vibrations is planned for the DD phase.

5.5.1.8 Static WFS Zero-point Calibration Error

We define static WFS zero-point calibration error as the residual wavefront error in the science beam at the completion of an internal NGAO wavefront calibration procedure. This 'flattening' of the science wavefront is typically limited by SNR in the calibration signal itself, for example using phase diversity techniques, or in stability of the system during a calibration routine.

Because zero-point (sometimes called 'centroid offset') calibration of the wavefront sensors includes error that are both inside and outside the spatial control bandwidth, we usually refer to the zero-point error as the error that could be correctable by the system DM, if it had better information. The wavefront errors that are uncorrectable by NGAO are allocated separately for the AO System (§5.5.1.14) and DAVINCI (§5.5.1.15).

5.5.1.9 Dynamic WFS Zero-point Calibration Error

Changes in the size and shape of the HO WFS subaperture PSF can result in a systematic error in the science wavefront. As subaperture PSF varies, non-linearities in the WFS slope response function results

in changes to the local wavefront shape for the same zero-point (aka centroid offset). This was a major limitation to the performance of the original Keck AO system¹⁶.

NGAO strategy is to induce a known, small amplitude tip-tilt signal (known as a small amplitude dither) into the beam, from which the changes in the slope response curve can be extracted through wavefront sensor telemetry analysis. Still, this process will be imperfect, so we allocate 25 nm RMS wavefront error for the residual dynamic changes in WFS zero-point.

5.5.1.10 Stale Reconstructor Error

Our architecture choice for the optical relay, including image stabilization with a K-mirror, results in the constant rotation of the image of the telescope stop on the LODM and other NGAO internal pupils. Because the illumination pattern is changing with time, the RTC reconstructor will need to be periodically updated to maintain top performance. Similarly, the tomographic fixed asterism reconstructor will need to be periodically updated to take into account changes in the turbulence profile and strength.

The NGAO error budget makes an allocation for the wavefront error due to an out-dated or 'stale' reconstructor of 15 nm RMS. The implication of this allocation to the interface to the Keck ${\rm C_n}^2(h,t)$ monitor and load times for new reconstructors in the RTC will be detailed in the DD phase. A study of the effect of rapid field rotation near zenith on the NGAO K-mirror was made in KAON 708, Limit to AO Observations from Altitude-Azimuth Telescope Mounts.

5.5.1.11 DM Finite Stroke Error

The NGAO architecture includes both LODM and HODM elements, increasing the available physical stroke for AO correction compared to the current Keck AO systems. Still, in poor seeing it becomes possible to saturate DM actuator stroke on one or the other of the mirrors.

KAON 721 models this effect crudely by estimating in a statistical sense the expectation value of the number of saturated actuators at a given time (assuming Gaussian statistics based on the RMS wavefront error). If, for example, 1% of the actuators are expected to saturate, we then assume the impact to the wavefront error budget is equivalent to an RMS wavefront error that reduces the Strehl ratio in the observing band by a factor of 0.99. Obviously, this is a crude model and even then more applicable to Strehl than EnsqE and EncE calculation (and not at all to high-contrast calculations). Still, for NGAO we rarely find ourselves concerned about finite stroke errors.

5.5.1.12 High-order Wavefront Aliasing Error

High spatial frequency wavefront aberrations above the Nyquist limit of our Shack-Hartmann NGS and LGS wavefront sensors can become aliased to appear incorrectly as low spatial frequency errors, which are then incorrectly imparted by the LODM onto the science beam.

KAON 721 includes the wavefront aliasing error proposed by Rigaut, Veran, and Lai (XXX) and supports a user-definable switch to reduce the amount of aliasing error if anti-aliasing stops are deployed in WFS's.

 $^{^{16}}$ van Dam, et al., "The W. M. Keck Observatory Laser Guide Star Adaptive Optics System: Performance Characterization," *PASP* 118:310-318, 2006.

For NGAO, we have elected not to include an anti-aliasing spatial filter in the LGS WFS, because relatively extended subaperture spot size precludes effective spatial filtering. In the NGS WFS, we have not included an anti-aliasing spatial filter to reduce costs. High-contrast science using NGS WFS on bright stars will be hampered by this decision, but this was not deemed to be a key science case for NGAO.

5.5.1.13 Go-to Control Errors

The NGAO science path correction architecture is based upon the expected efficacy of go-to HODM control. KAON 721 allocates a total of 30 nm RMS wavefront error to effects specific to go-to control. KAON 723 flows this error down into the following terms:

- Incorrect measurement of LODM
 - Go-to control relies upon successful knowledge of the state of the LODM. This
 allocation levels requirements on LODM position knowledge that will be further
 explored in the DD phase.
- Incorrect calibration of LGS WFS
 - Residual non-linearities in the LGS WFS will corrupt the wavefront measurement which
 is then applied to the HODM. In a traditional closed-loop AO system, this error would
 be sensed and corrected in subsequent loop updates, but for NGAO we must know the
 true wavefront shape accurately.
- Geometric uncertainties
 - Non-uniform WFS subaperture of HODM actuator spacing may induce science wavefront errors separate from pupil registration errors between WFS's and DM's accounted for in §5.5.1.16.
- Incorrect actuation of MEMS DM's
 - The difference between commanded actuator position and actual position arrived at by a HODM actuator (as validated on the VILLAGES testbed.)

5.5.1.14 Uncorrectable AO System Aberrations

Internal AO system aberrations outside the spatial bandwidth of the HODM, or those imparted by optics removed from a system pupil, can induce uncorrectable AO system aberrations. KAON 721 allocates 33 nm RMS wavefront error to all uncorrectable AO system aberrations, while KAON 723 flows this error down onto specific surface quality requirements for each of the NGAO optics.

5.5.1.15 Uncorrectable Instrument Aberrations

Internal instrument aberrations that are outside the spatial bandwidth of the HODM, or are field dependent, cannot be corrected by NGAO. KAON 721 allocates 30 nm RMS to uncorrectable instrument aberrations for DAVINCI on-axis and 60 nm RMS at the edge of a 20 arcsec radius FoV.

5.5.1.16 DM-to-lenslet Pupil Mapping Errors

NGAO has a complex set of WFS and DM pupil mapping requirements. KAON 721 makes a high-level allocation of 21 nm RMS in the fixed LGS asterism path and 28 nm RMS in the patrolling LGS asterism path. During the PD phase, we elaborated upon this in KAON 723, flowing sub-allocations of this error

with increasing detail. Evaluation of each possible registration error, however, proved too expensive in terms of computational and human effort for the PD phase. As a working estimate, we adopted a general tolerance that actuator and lenslet pupils should all be set and remain registered to the LODM (an adopted pupil fiducial) to less than 5% of the smallest subaperture spacing. Thus, for PD, engineering choices like the thermal stability within the cold enclosure (+/- 1C) are based on requiring 5% of a 1/60th aperture = 1/1200 of the pupil. The working tolerance was based on the collective experience of the NGAO team in having fielded numerous AO systems with typically 10% of a 1/20 pupil subaperture, including performance degradation experience for systems having pupil misregistration flexure. Our judgment was that for NGAO, a factor of 6 tighter tolerance would be sufficient to meet the 21 nm residual wavefront allocation. KAON 704, Opto-mechanical Registration Tolerances for "goto" Adaptive Optics explores this tolerance in more detail.

In the DD phase, we will seek to confirm this experiential evidence and perform more detailed Monte Carlo analysis of NGAO pupil misregistrations. To save costs, we intended to make random misregisration draws from probability distributions built with our registration tolerances, and perform only forward performance evaluations (e.g. we do not intend to calculate sensitivity matrices for each pupil parameter within NGAO.)

5.5.1.17 Angular Anisoplanatism

As a singly-conjugated AO system, NGAO performance will fall as a function of normal angular anisoplanatism (Hardy Ch. 3.7.2, pg 102). KAON 721 encodes angular anisoplanatism error as a function of the field radius (1/2 the FoV) of each specific NGAO science case (thus, our WFE's are already the worst case for the science case described.)

Our calculation of θ_0 , the angular coherence parameter, takes into account the finite Keck aperture, so is somewhat increased relative to the usually assumed infinite aperture isoplanatic angle.

5.5.1.18 High-order Wavefront Error Margin

To account for unforeseen sources of residual high-order wavefront error, we include in the NGAO error budgets a margin of 45 nm RMS, which is added in quadrature to the known, estimable errors. During DD phase, we reserve the option to allocate some or all of this error through revisions to the performance flowdown.

5.5.1.19 Other High-order Wavefront Errors

Additional high-order wavefront errors are carried in the NGAO error budgets, but due to their relatively small magnitude, we will only refer to them here as:

- Asterism Deformation Error
- Chromatic Error
- Dispersion Displacement Error
- Scintillation Error
- WFS Scintillation Error
- DM Hysteresis Error
- DM Drive Digitization Error

An interested reader is invited to review the implementation of these error terms in KAON 721. Note, some of these errors are simple allocations for the PD phase.

5.5.2 Tip-tilt Wavefront Errors

5.5.2.1 Tip-tilt Bandwidth Error

KAON 721 assumes a traditional single-pole model of tip-tilt bandwidth error,

$$\sigma_{TT\;Bandwidth} = \left(\frac{f_{T}}{f_{-3dh}}\right) \left(\frac{\lambda}{D}\right) \sqrt{\cos{(\zeta)}}\; arcsec$$

Where f_T is the effective tilt tracking frequency (Hardy, Eqn. 9.64, pg 345), evaluated at the observing zenith angle, ζ , and f_{-3db} is the tilt servo rejection bandwidth. Typically, we evaluate at $\lambda = 500$ nm, to find $f_T \sim 1.2$ Hz at $\zeta = 30$ deg, after applying a correction for the impact of our Keck-assumed $L_0 = 50$ m outer scale of turbulence (compare Hardy Eqn. 7.63, pg 255 and Eqn. 9.8, pg 315).

5.5.2.2 Residual Telescope Pointing Jitter Error

The Keck Telescopes have a well known pointing jitter oscillation that, without additional consideration, would limit the ability of NGAO to meet its science goals. KAON 680, "Vibration Mitigation" considers this effect in detail. KAON 721 assumes the successful mitigation of pointing jitter using one or more of these mitigations to an input disturbance level of only 1 milliarcsec RMS, a factor of between 10x and 20x improvement over the telescope jitter seen with the current Keck AO system (KAON 680). Because this jitter is observed at high temporal frequency (typically 29 Hz), the regular NGAO tip-tilt rejection loop is limited in its corrective ability. Thus, any shortfall in our control of input jitter will map directly to NGAO performance, particularly for high-sky-coverage science programs, where NGS photon scarcity precludes high-bandwidth operation. As can be seen from Table 2, our final tip-tilt error requirements are of the order of 3-5 milliarcsecond residual one-axis tip-tilt error, so any failure to control input jitter to at least this level would have a significant impact on performance.

5.5.2.3 Tip-tilt Measurement Error

Tip-tilt measurement error is calculated based upon the number and type of wavefront sensor used for tip-tilt sensing. For NGAO, there are three distinct modes of tip-tilt sensing: with the LO WFS at IR wavelengths, with the NGS WFS in 5x5 subapertures while operating in LGS mode, and with the NGS WFS in 60 x 60 mode while operating in NGS mode. In each of these cases, we use the same measurement error equation at in $\S5.5.1.3$, omitting the error propagator term, E_p .

SNR calculations for TT sensing include the same physical effects as for high-order wavefront sensing. However, because we frequently use near-infrared wavelengths for tip-tilt, we have to be careful to consider the impact of thermal noise background, which is a function of the architecture of the specific wavefront sensor (for example, the inclusion of a cold stop is typically used to limit thermal irradiance).

For the NGAO LO WFS, which utilizes between 1 and 3 NGS for tip-tilt sensing, we calculate the measurement error in ensemble, forming the signal from the total photoflux from 1, 2, or 3 stars (whose brightnesses are related to the sky coverage calculation described in XXX) and the noise term from all the noise sources across all tip-tilt sensors. Thus, we add up all the pixels in the tip-tilt measurement,

for example, which in the case of 2 TT + 1 TTFA sensors, sampled with 2x2 pixels per subimage, would equal 2*(2x2) + 1*4*(2x2) = 20 pixels, where the TTFA is assumed to be a 2x2 subaperture Shack-Hartmann sensor. Thus, the total flux from 3 stars, and noise (and background, etc.) from 20 pixels are included in the tip-tilt measurement error calculation.

KAON 721 currently does not support the inclusion of thermal background noise between near-infrared bands (e.g. between J and H atmospheric bands). Although we have considered a LO WFS filter combination that blocks the inter-band OH emissions as a design choice, in the DD phase we will confirm the need or non-need for this complication based on cost and the impact of these additional sky noise photons.

Tip-tilt measurements made with the NGS WFS are more straightforward, using the same options as described in §5.5.1.3, independent of choices made for the HO WFS. In the LGS observing mode where the science target itself is used for both tip-tilt and blind mode measurement, NGAO has the additional benefit of suffering no tip-tilt anisoplanatism. KAON 721 supports an intermediate method of calculating partially corrected visible light PSF's within the relatively large 5x5 (~2.2 meter diameter) subapertures, following the analysis of Femenia (REF XXX), but this is not invoked for NGAO.

5.5.2.4 Tip-tilt Anisoplanatism Error

The tip-tilt error measured by an off-axis NGS will differ from that appropriate for an on-axis science target. This TT anisoplanatism is described quantitatively by Hardy (Ch. 7.4.2, pg 250).

In the case of NGAO, where we will employ multiple NGS for TT measurement, we assume a reduction in TT anisoplanatism, based upon the likely reduction in nearest-neighbor distance in a random star field. For N = 2 TT stars, KAON 721 assumes the effective NGS off-axis distance is 0.67 times the distance of the brighter NGS, while for N=3 the effective off-axis distance is 0.53 times this amount. This is conceptually equivalent to the idea of using TT measurement averaging to reduce TT anisoplanatism, but does not include more detailed considerations, such as optimal TT estimation based upon NGS off-axis distance, SNR, color similarity to the science target, etc.

In the DD phase, we will consider the cost/benefit of further expanding this TT averaging analysis using more detailed wave-optics simulations.

5.5.2.5 Centroid Anisoplanatism Error

Dekens¹⁷ describes the effect of aliasing of coma and other higher-order wavefront errors as an apparent (and incorrect) TT residual error. This was a source of concern at the PDR for the original Keck AO system, as the calculated effect was considerable. Actual Keck AO experience has shown, however, that the worrisome magnitude of centroid anisoplanatism error was not realized. It has been postulated that the effects of finite integration time averaging or finite servo bandwidth mitigate this effect to some level (P. Wizinowich, private communication), but a reliable post-mortem analysis of centroid anisoplanatism in the current Keck AO system has not been performed.

¹⁷ Dekens, F. "Atmospheric characterization for adaptive optics at the W. M. Keck and Hale telescopes," PhD thesis, UCI, 1999.

KAON 721 allocates 0.55 milliarcseconds of CA error, a factor of 20 reduction over the predictions by Dekens which are known to be overly pessimistic.

This remains perhaps the most uncertain term in the TT error budget and will be further considered in the DD phase. We have not agreed upon a more detailed analysis approach, but will consider the applicability of detailed LAOS simulations to better understanding this issue.

5.5.2.6 Atmospheric Dispersion Error

Maintaining small image size in the science path requires excellent correction of atmospheric dispersion errors. KAON 721 currently handles ADC improvement over inherent atmospheric dispersion as providing a factor of 20x improvement (and so this is a function of observing band). During DD phase, we will replace this model with one based upon the performance of our actual ADC design, appropriate to each observing band.

5.5.2.7 Non-common Path Tip-tilt Errors

Residual thermal flexure between the science instruments and the sensors providing TT information (the LO WFS in LGS mode, or the NGS WFS in NGS mode) will lead to blurring of the AO PSF. KAON 721 allocates for non-common-path TT errors a value of 3.2 mas / hr, which KAON 723 flows down into items such as thermal stability of the NGAO optical bench, thermal stability interior to the LOWFS, etc.

5.5.2.8 Tip-tilt Error Margin

To account for unforeseen sources of residual tip-tilt error, we include in the NGAO error budgets a margin of 2.0 milliarcseconds. During DD phase, we reserve the option to allocate some or all of this error through revisions to the performance flowdown.

5.5.3 Tip-tilt Sharpening Budget

KAON 721 includes a separate high-order wavefront error budget for the patrolling LGS-based AO system used to sharpening NGS in the LO WFS. The NGAO architecture calls for asynchronous operation of the combined patrolling LGS / LO WFS DM correction subsystem, allowing for independent optimization of key sharpening budget parameters, such as the amount of laser power dedicated to each patrolling LGS and the frame rate of the patrolling LGS WFS's.

The performance benefit of go-to control sharpening of TT NGS was reported upon in Dekany, 2008 (XXX), from which the NGAO project justified the additional expense and complexity of a TT sharpening system. As part of the Build-to-Cost project rescope (see KAON 642), the NGAO team looked closely at the science priorities and the cost/benefit of numerous design options, and elected to retain the TT sharpening subsystem based upon the high priority given to wide-sky-fraction operation of NGAO.

5.5.4 Truth WFS Budget

KAON 721 contains a separate error budget to estimate the fidelity with which the visible TWFS can measure slow variations in the correction calibrations. The TWFS budget includes consideration of the measurement error, the bandwidth error, atmospheric averaging, and other details to determine the residual error for each TWFS measurement.

During PD phase, we concentrated on the focus error component tracked by the TWFS, but have not had the opportunity to fully understand TWFS performance on other wavefront modes. In part, we expect our strategy of small amplitude TT dithering for LGS WFS gain calibration, to help mitigate the relatively large contribution of 'input' wavefront error that must be sensed with the TWFS in the current Keck AO system.

5.6 "Sky Coverage" Sheet

KAON 721 provides a number of optionally selectable star density models with which to calculate sky coverage fraction. NGAO calculations are made using the near-IR stellar density models from Spagna, which is parameterized by galactic latitude.

Our approach to multiple guide star TT performance is to 1) determine the off-axis distance and brightness of NGS that satisfies the NGAO science case's proscribed sky coverage fraction, 2) determine the brightness of other NGS in the field that are 'highly likely' to be found closer to the science target than the initial star, 3) repeat for a third star, 4) use the sum of photofluxes from all three stars to determine TT measurement errors. Using this approach, we find statistically that for a 'brightest star' brightness of V = 18 at off-axis distance R, the brightest star highly likely to be interior to a circle of radius R will be 0.28 times as bright (e.g. V = 19.3), and the 3^{rd} star within the circle of radius R will be 0.135 times as bright as the original (e.g. V = 20.2).

Infrared star density models based on more complete and more recent publications, such as that described by Robin et al. ¹⁸ exist, and integration of these models into KAON 721 is noted as an area for future implementation (see §5.7)

5.7 Wavefront Error Budget Validation

5.7.1 Keck II LGS Performance Validation

To gain specific confidence in the fidelity of KAON 721 when applied to NGAO, an SDR trade study was performed using KAON 721 to model both the existing performance of the Keck 2 AO system and replicate the predictions for Keck 1 LGS made by Keck Observatory staff. This study, KAON 461, "Wavefront Error Budget Predictions & Measured Performance for Current & Upgraded Keck AO" fundamentally validated the simulation- and analysis-based engineering approach of KAON 721. Comparisons were made for each of:

- NGS mode performance (V = 8)
- LGS mode performance with bright NGS tip-tilt star (V = 10)
- LGS mode performance with faint NGS tip-tilt star (V = 18)

Although a strict quantitative term-by-term comparison of terms was difficult (due to uncertainties in knowledge of the 'on-sky' atmospheric $C_n^2(h)$ profile, which effects e.g. isoplanatic angle, both the overall budget predictions and the trends were consistent in all cases.

¹⁸ Robin, A. C., Reylé, C., Derrièrre, S., and Picaud, S., "A synthetic view on structure and evolution of the Milky Way", 2003, Astron. Astrophys., 409:523 (erratum: 2004, Astron. Astrophys., 416:157).

5.7.2 Comparison of NGAO and NFIRAOS Error Budgets

One of the recommendations of the SDR review panel was to also undertake a detailed error budget comparison between the Keck NGAO and TMT NFIRAOS AO systems. This study, KAON 629, "Error Budget Comparison with NFIRAOS", systematically accounted for differences in the AO architecture (science path go-to AO augmented with dual AO LO WFS sharpening for NGAO and multi-conjugate AO for NFIRAOS) and compared the two team's performance analyses on an equal input basis.

The most significant finding for the NGAO budget was the (known) double counting of certain high-frequency error terms that arise from independent evaluation of engineering budget models. Specifically, high-spatial-frequency errors counted as fitting error (§5.5.1.1) is also counted as a spatial frequency component of bandwidth error (§5.5.1.2). The assumption of error term independence is indeed a compromise made in the KAON 721 formalism. However, it tends to be a conservative one in that it tends to modestly underestimate system performance (thus, can be seen as another source of performance margin.)

Similarly, the KAON 629 highlighted the fundamentally different approach to sky coverage estimation between the two projects. While NGAO follows the approach described in §5.6, NFIRAOS uses a Monte-Carlo strategy of generating a large pool of candidate NGS asterisms in a field and evaluating the low-order 'blind mode' compensation and residual tip-tilt errors in order to estimate a median (or Nth percentile) probability of system performance as a function of galactic latitude.

The two approaches were directly compared earlier in the NGAO SD phase in KAON 470, "Keck NGAO sky coverage modeling". In that report, the approaches were found to be essentially equivalent in their conclusion for NGAO performance, although the more detailed Monte-Carlo technique was shown to provide more information on the source of residual errors than the (more computationally efficient) engineering spreadsheet model. It is interesting to note that during subsequent analysis of the KAON 721 during the PD phase, Chris Neyman uncovered a numerical 'factor of two' error in the implementation of the Spagna star density model that was not uncovered by the earlier KAON 470, but that upon reoptimization of tip-tilt NGS off-axis distance, brightness, and LO WFS frame rate (which is also noise dependent) resulted in only a modest revision to sky coverage performance, which presumably masked the effect during the KAON 470 study.

Overall, when normalized to equivalent input parameters, the NGAO and NFIRAOS error budget approaches were in KAON 629 demonstrated to yield strongly similar results, providing additional confidence to the KAON 721 approach that had already been anchored through years of Palomar Observatory experience and the detailed Keck comparisons in KAON 461.

5.8 Configuration Control

KAON 721 is an NGAO configuration controlled document, meaning that revisions to the wavefront error budget spreadsheet is subject to the change control procedures described in KAON 638, "Requirements Approval and Change Process." R. Dekany maintains KAON 721, which includes a worksheet (named "WFE Tool To-Do List") that tracks known issues with calculations or assumptions in the tool, as well as version history and a summary of corrective actions.

The NGAO system architecture choices are documented in the configuration region of the Input Summary tab of the Wavefront Error Budget Tool, KAON 721. Not shown here, but critical to budget fidelity, is an area of the Input Summary that selects optical pass-bands for each WFS camera. (Also not shown are optical transmission models that track expected photon transmission through each AO system configuration.)

6 Detailed Error Budget for Galaxy Assembly Key Science Case

To further illuminate the structure and usage of KAON 721 in evaluating NGAO performance prediction and requirements flowdown, we will now consider the key elements of the tool as generated for one of our key science cases, Galaxy Assembly. The observing scenario information for Galaxy Assembly is included in Table 4.

6.1 Science Path Wavefront Error Budget

The science path wavefront error budget from the 'Optim' sheet of KAON 721 is shown in Table 6. This table is organized (from top-to-bottom) into:

- A heading section, including the AO system configuration and science case name
- An upper high-order wavefront error section
 - Including several key parameters relevant to the underlying calculations in a 'Parameter" column
 - This section is further subdivided loosely into 'fundamental', 'implementation', and 'anisoplanatism' error subsections.
 - Light-blue highlighting in the table generally represents error allocations, e.g. quantities not derived from underlying physical calculations. These are typically further flowed down to subsystem functional requirements in KAON 723.
- A tip-tilt error section
 - Wherein errors are natively calculated in units of residual tip-tilt in milliarcseconds, then converted (via the tip-tilt Strehl ratio and thereafter the primary observing passband wavelength) into equivalent RMS wavefront error estimates, to facilitate the calculation of an 'effective RMS wavefront error' which correctly predicts Strehl performance from the combination of high-order and residual tip-tilt errors
- Strehl predictions
 - Presented as a function of different observing bands, defined in the top-right of the table
- Ensquared and encircled energy predictions
 - For the primary observing band defined by science case, for a range of different spaxel dimensions (e.g. "Spaxel / Aperture Diameter")
 - A choice of encircled or ensquared energy is provided in a (yellow, input) cell
- FWHM predictions
- Sky coverage validation

- Showing the sky coverage corresponding to the tip-tilt NGS star of the brightness and off-axis distance indicated in the heading section, which is optimized to equal the sky coverage fraction required for each science case (Table 1).
- And finally a section summarizing many of the key system parameters (not previously cited in the HO and TT error sections).
 - These include atmospheric parameter, number of TT WFS, the optimized WFS frame rates, detector read noises, etc.

Op	timizations/sky co	verage	calcu	lations					COO	/ NG	AO F	ROP	RIETA	ARY			
Ľ																	
	Purpose:						changing parameters nput Summary cells p		purple o	ells here	2						
		How exa	ctly to opt	imize depends	on whether the	cience	case is NGS, LGS on-ax	is, or LGS t	ield stan	s (sky co	verage)						
	Solver Input Values	NGS	LGS		Current Set	ings		Optimi	zation Co	ontrols (t	e carefi	ıl & und	erstand I	now the	se intera	ct with S	Solver befo
	HO guide star brightness	LGS		mV	57	PDE/s	ubap/exp	Optimiz	e LGS O	f-Pointing	9?	N					
	Optim HO integration time: Optim subaperture width:	0.00050		sec	948	Hz			e LGS Ra			N N			Non-ontin		
	TT guide star brightness	0.174 LGS		meters mV	14.11	Subap: mKs	5	Optimi	ze Subap	Diamete	err	IN	0.182	m	Non-optii	m subap	widin
	TT integration time TT guide star distance	0.00050		sec arcsec	213												
	TWFS guide star birghtness	LGS	19.0														
	TWFS integration time TWFS guide star search radius	0.0		sec arcsec	0.37	Hz											
	Number of laser beacons		4.0														
	LGS asterism radius	0.0	0.167	arcmin	Set ast rad =	0.001 fr	or single LGS	Optimi	ze LGS as	terism ra	adius?	N	< not y	et imple	mented (11/18/08)
	ck Wavefront Erro	r Budg	et Su	nmary	Version 2.1				u'	-1	r	Scie	ence E	Band Y	J		К
Mod	e: NGAO LGS ument: DAVINCI							λ (μμ	0.36	g' 0.47	0.62	0.75	0.88	1.03	1.25	H 1.64	2.20
Sci. 0	Observation Galaxy Assembly							δλ (μμ)		0.14		0.15	0.12	0.12	0.16	0.29	0.34
								./Δ (μασ)	6.7	8.8	11.6	14.1	16.6	19.4	23.5	30.8	41.4
Sci	ence High-order Err	ors (LG	S Mod	le)	Wavefr		Paramet	er				Stre	hl Rat	io (%)			
-				-,	Error (r	ms)	1	-									
	Atmospheric Fitting Error					nm	60 Subaps										
	Bandwidth Error High-order Measurement Erro	Vr.			61	nm nm	47 Hz (-3db) 50 W										
	LGS Tomography Error				37	nm	4 sci beacon(s)									
	Asterism Deformation Error Chromatic Error					nm nm	0.50 m LLT Upper limit										
	Dispersion Displacement Erro	r			1	nm	Estimate										
	Multispectral Error Scintillation Error		К			nm nm	30 zen; sci wav 0.34 Scint index a	t 0.5um	-								
	WFS Scintillation Error				10	nm	Allocation										
\vdash	Uncorrectable Static Telescop	e Aberrati	ons	115 nm		nm	64 Acts Across	Pupil									\vdash
	Uncorrectable Dynamic Telesi	ope Aben	rations		37	nm	Dekens Ph.I)									
	Static WFS Zero-point Calibrat Dynamic WFS Zero-point Calib				25	nm nm	Allocation Allocation										
	Leaky Integrator Zero-point C Stale Reconstructor Error				10	nm nm	Allocation Allocation										
	Go-to Control Errors				30	nm	Allocation										
	Residual Na Layer Focus Chan DM Finite Stroke Errors	ge				nm nm	30 m/s Na layer 5.3 um P-P stroi										
	DM Hysteresis				13	nm	from TMT me										
1	High-Order Aliasing Error DM Drive Digitization					nm nm	60 Subaps 16 bits										
	Uncorrectable AO System Abe				33	nm	Allocation										
	Uncorrectable Instrument Abo DM-to-lenslet Misregistration					nm nm	DAVINCI Allocation		-								\vdash
	DM-to-lenslet Pupil Scale Erro				15	nm	Allocation										
	Angular Anisoplanatism Error			101 nm		nm	1.0 arcsec										
	HO Wavefront Error Margin					nm	Allocation										
H	Total High Order Wa	vefron	t Error	153 nm	160	nm	High Order S	Strehl	0.00	0.01	0.07	0.17	0.28	0.40	0.53	0.69	0.82
F									F								\Box
Sci	ence Tip/Tilt Errors			Angula Error (rm			Paramet	er				Jurel	nl ratio	JO (%)			
Е	Tilt Money	avie'	Sci Filter				19.0										
	Tilt Measurement Error (one- Tilt Bandwidth Error (one-axis)	dXIS)		1.94 ma 1.28 ma	is 22	nm nm	19.0 mag (mV) 9.6 Hz (-3db)										
		-axis)		3.23 ma 0.55 ma		nm nm	42.0 arcsec from 20 x reduction	sci									
	Tilt Anisoplanatism Error (one	ticm							1								
	Residual Centroid Anisoplana Residual Atmospheric Dispers	ion	К	0.12 ma		nm	20 x reduction										
	Residual Centroid Anisoplana Residual Atmospheric Dispers Induced Plate Scale Deformat	ion ions	К	0.12 ma 0.00 ma	is C	nm nm	0 m conj heig	nt									
	Residual Centroid Anisoplana Residual Atmospheric Dispers Induced Plate Scale Deformat Non-Common-Path Tip-Tilt Er Residual Telescope Pointing J	ion ions rors		0.12 ma 0.00 ma 1.60 ma 1.21 ma	is 0 is 27 is 21	nm nm nm nm	0 m conj heig 3.2 mas/l Allocation 29 Hz input dis										
	Residual Centroid Anisoplana Residual Atmospheric Dispers Induced Plate Scale Deformat Non-Common-Path Tip-Tilt Er	ion ions rors		0.12 ma 0.00 ma 1.60 ma	is 0 is 27 is 21	nm nm nm	0 m conj heig 3.2 mas/l Allocation										
	Residual Centroid Anisoplana Residual Atmospheric Dispers Induced Plate Scale Deformat Non-Common-Path Tip-Tilt Er Residual Telescope Pointing J	ion ions rors itter (one-	axis)	0.12 ma 0.00 ma 1.60 ma 1.21 ma	is (1) is 27 is 21 is 195	nm nm nm nm	0 m conj heig 3.2 mas/l Allocation 29 Hz input dis	turbance	0.27	0.39	0.53	0.62	0.70	0.76	0.82	0.89	0.94
	Residual Centroid Anisoplana Residual Atmospheric Dispers Induced Plate Scale Deformat Non-Common-Path Tip-Tilt Er Residual Telescope Pointing J TT Error Margin	ion ions rors itter (one-	axis)	0.12 ma 0.00 ma 1.60 ma 1.21 ma 2.00 ma	is (1) is 27 is 21 is 195	nm nm nm nm	0 m conj heig 3.2 mas/l Allocation 29 Hz input dis Allocation	turbance	0.27	0.39	0.53	0.62	0.70	0.76	0.82	0.89	0.94
	Residual Centroid Anisoplana Residual Atmospheric Dispers Induced Plate Scale Deformat Non-Common-Path Tip-Tilt Er Residual Telescope Pointing J TT Error Margin	ions ions rors itter (one-	axis)	0.12 ma 0.00 ma 1.60 ma 1.21 ma 2.00 ma	is (1) (1) (2) (3) (4) (4) (4) (4) (4) (4) (4) (4) (4) (4	nm nm nm nm	0 m conj heig 3.2 mas/l Allocation 29 Hz input dis Allocation Tip/Tilt Str	ehl	0.27	0.39		0.62	0.70	0.76	0.82	0.89	0.94
	Residual Centroid Anisoplana Residual Atmospheric Dispers Induced Plate Scale Deformat Non-Common-Path Tip-Till Er Residual Telescope Pointing J TT Error Margin	ions ions rors itter (one-	axis)	0.12 ma 0.00 ma 1.60 ma 1.21 ma 2.00 ma	is (1) (1) (2) (3) (4) (4) (4) (4) (4) (4) (4) (4) (4) (4	nm nm nm nm nm	0 m conj heig 3.2 mas/l Allocation 29 Hz input dis Allocation Tip/Tilt Str	ehl	0.00	0.00	0.04	0.11	0.20	0.30	0.44	0.61	0.76
	Residual Centroid Anisoplana Residual Atmospheric Dispers Induced Plate Scale Deformat Non-Common-Path Tip-Till Er Residual Telescope Pointing J TT Error Margin	ions ions rors itter (one-	axis)	0.12 ma 0.00 ma 1.60 ma 1.21 ma 2.00 ma	is (1) (1) (2) (3) (4) (4) (4) (4) (4) (4) (4) (4) (4) (4	nm nm nm nm nm	0 m conj heig 3.2 mas/l Allocation 29 Hz input dis Allocation Tip/Tilt Str	ehl		0.00			0.20	0.30	0.44		0.76
	Residual Centroid Anisoplana Residual Atmospheric Dispers Induced Plate Scale Deformat Non-Common-Path Tip-Till Er Residual Telescope Pointing J TT Error Margin	ions ions rors itter (one-	axis)	0.12 ma 0.00 ma 1.60 ma 1.21 ma 2.00 ma	ss (1) (1) (1) (1) (1) (1) (1) (1) (1) (1)	nm nm nm nm nm	0 m conj heig 3.2 mas/l Allocation 29 Hz input dis Allocation Tip/Tilt Str	ehl	0.00	0.00	0.04	0.11	0.20	0.30	0.44	0.61	0.76
To	Residual Centroid Anisoplana Residual Atmospheric Dispers Induced Plate Scale Deformat Non-Common-Path Tip-Till Er Residual Telescope Pointing J TT Error Margin	ions ions rors itter (one-	axis)	0.12 ma 0.00 ma 1.60 ma 1.21 ma 2.00 ma	ss (1) (1) (1) (1) (1) (1) (1) (1) (1) (1)	nm nm nm nm nm	0 m con) heig 3.2 mssl Allocation 29 ltz inperiod Allocation Tip/Tilt Str Total Streh FWHM (m neter (mas) 15 Square 0.0	ehl (%) as) 35 9 0.36	0.00 8.3 50 0.56	0.00 10.1 70 0.75	0.04 12.6 90 0.81	0.11 14.9 120 0.83	0.20 17.3 240 0.85	0.30 20.0 400 0.88	0.44 24.1 800 0.92	31.2	0.76
To	Residual Centroid Anisoplana Residual Atmospheric Disperi Induced Plate Scale Deformat Non-Common-Path Tip-Till Er Residual Telescope Pointing 3 T Total Tip/Tilk Error (tal Effective Wavefro	ions ions rors itter (one-	axis)	0.12 ma 0.00 ma 1.60 ma 1.21 ma 2.00 ma	ss (1) (1) (1) (1) (1) (1) (1) (1) (1) (1)	nm nm nm nm nm	0 m conj heig 3.2 mas/l Allocation 29 Hz input dis Allocation Tip/Tilt Str Total Streh FWHM (m	ehl (%) as) 35 9 0.36	0.00 8.3 50 0.56	0.00 10.1 70 0.75	0.04 12.6 90 0.81	0.11 14.9 120 0.83	0.20 17.3 240 0.85	0.30 20.0 400 0.88	0.44 24.1 800 0.92	31.2	0.76 41.7
To	Residual Centroid Anisoplana Residual Atmospheric Disperi Induced Plate Scale Deformat Non-Common-Path Tip-Till Er Residual Telescope Pointing 3 T Total Tip/Tilk Error (tal Effective Wavefro	ions ions rors itter (one-	axis)	0.12 ma 0.00 ma 1.60 ma 1.21 ma 2.00 ma	as 91 182	nm nm nm nm nm	0 m con) heig 3.2 mssl Allocation 29 ltz inperiod Allocation Tip/Tilt Str Total Streh FWHM (m neter (mas) 11 Square 0.0	ehl (%) as) 35 9 0.36	0.00 8.3 50 0.56	0.00 10.1 70 0.75	0.04 12.6 90 0.81	0.11 14.9 120 0.83	0.20 17.3 240 0.85	0.30 20.0 400 0.88	0.44 24.1 800 0.92	31.2	0.76 41.7
To	Residual Centroid Anisoplana Residual Atmospheri Oisperi Induced Plate Scale Deformat Non-Common-Part Injenite Residual Telescope Pointing J TT Enror Magn Total Tip/Titt Error (tal Effective Wavefro squared Energy Coverage	ions ions rors itter (one- one-ax	axis) is) r	0.12 me 0.00 mm 1.00 mm 1.21 mm 1.20 mm 1.21 mm 1.21 mm 1.21 mm 1.21 mm 1.20 mm 1.21 mm 1.20 mm 1.21 mm 1.20 m	ss 27 ss 27 ss 27 ss 91 ss 198 as 91 182	nm nm nm nm nm nm	Om con lete 3.2 mas/l Allocation 29 the input dis Allocation Tip/Tilt Str Total Streh FWHM (m neter (mas) 1: Square 0.0. Seeing-Limited 0.0.	ehl (%) as) 35 9 0.36 0 0.00	0.00 8.3 50 0.56 0.01	0.00 10.1 70 0.75 0.02	0.04 12.6 90 0.81 0.03	0.11 14.9 120 0.83 0.05	0.20 17.3 240 0.85	0.30 20.0 400 0.88	0.44 24.1 800 0.92	31.2	0.76 41.7
To	Residual Centroid Anisoplana Residual Atmospheri Oisperi Induced Plate Scale Deformat Non-Common-Part In Junit 12 Residual Telescope Pointing J TT Emor Margin Total Tip/Tilt Error (tal Effective Wavefro	ions ions rors itter (one- one-ax	axis) is) r	0.12 me 0.00 mm 1.00 mm 1.21 mm 1.20 mm 1.21 mm 1.21 mm 1.21 mm 1.21 mm 1.20 mm 1.21 mm 1.20 mm 1.21 mm 1.20 m	as 91 182	nm nm nm nm nm nm	0 m con) heig 3.2 mssl Allocation 29 ltz inperiod Allocation Tip/Tilt Str Total Streh FWHM (m neter (mas) 11 Square 0.0	ehl (%) as) 35 9 0.36 0 0.00	0.00 8.3 50 0.56 0.01	0.00 10.1 70 0.75 0.02	0.04 12.6 90 0.81 0.03	0.11 14.9 120 0.83 0.05	0.20 17.3 240 0.85	0.30 20.0 400 0.88	0.44 24.1 800 0.92	31.2	0.76 41.7
To En	Residual Centroid Anisoplana Residual Atmospheri Oisperi Induced Plate Scale Deformat Non-Common-Part Injenite Residual Telescope Pointing J TT Enror Magn Total Tip/Titt Error (tal Effective Wavefro squared Energy Coverage	cone-ax	axis) is) r	0.12 me 0.00 mm 1.00 mm 1.21 mm 1.20 mm 1.21 mm 1.21 mm 1.21 mm 1.21 mm 1.20 mm 1.21 mm 1.20 mm 1.21 mm 1.20 m	ss 27 ss 27 ss 27 ss 91 ss 198 as 91 182	nm nm nm nm nm nm	Om con lete 3.2 mas/l Allocation 29 the input dis Allocation Tip/Tilt Str Total Streh FWHM (m neter (mas) 1: Square 0.0. Seeing-Limited 0.0.	ehl (%) as) 35 9 0.36 0 0.00	0.00 8.3 50 0.56 0.01	0.00 10.1 70 0.75 0.02	0.04 12.6 90 0.81 0.03	0.11 14.9 120 0.83 0.05	0.20 17.3 240 0.85	0.30 20.0 400 0.88	0.44 24.1 800 0.92	31.2	0.76 41.7
To En	Residual Centroid Anisoplana Residual Atmospheric Dispersion John Common Paper Dispersion of the Common Paper Dispersion of	one-ax cover	axis) is) r	0.12 mm 1.20 mm 1.20 mm 1.21 m	182 182 182 182 182 182 182 182	nm nm nm nm nm nm	Om con lete 3.2 mas/l Allocation 29 the input dis Allocation Tip/Tilt Str Total Streh FWHM (m neter (mas) 1: Square 0.0. Seeing-Limited 0.0.	ehl (%) as) 35 9 0.36 0 0.00	0.00 8.3 50 0.56 0.01	0.00 10.1 70 0.75 0.02	0.04 12.6 90 0.81 0.03	0.11 14.9 120 0.83 0.05	0.20 17.3 240 0.85	0.30 20.0 400 0.88	0.44 24.1 800 0.92	31.2	0.76 41.7
To En	Residual Centroid Anisoplana Residual Atmospheric Dispersion John Common Paper Dispersion of the Common Paper Dispersion of	cover	is) r K age	0.12 mm 1.20 mm 1.20 mm 1.21 m	182 182 182 182 182 182 182 182	nm nm nm nm nm nm nm	Om con helps 3.2 mast/Allocation 3.2 mast/Allocation Allocation Al	ehl (%) as) 35 9 0.36 0 0.00	0.00 8.3 50 0.56 0.01	0.00 10.1 70 0.75 0.02	0.04 12.6 90 0.81 0.03	0.11 14.9 120 0.83 0.05	0.20 17.3 240 0.85 0.20	0.30 20.0 400 0.88	0.44 24.1 800 0.92 0.90	31.2	0.76 41.7 40 0.50
To En	Residual Centroid Anisoplana Residual Atmospheric Obsperi Induced Plate Scale Deformat Non-Common - Path Tip-Till E. Residual Atmospheric Obsperi Tenro Margin Tenro Margin Tenro Margin Tenro Margin Tenro Margin Control	one-ax Cover Covers 30 0.147	is) r K age	0.12 mm 1.20 mm 1.20 mm 1.21 m	182	nm nm nm nm nm nm nm deg	Om con help 29 has placed in a	ehl (%) as) 35 9 0.36 0 0.00	0.00 8.3 50 0.56 0.01 ted to the	0.00 10.1 70 0.75 0.02 Total Eff	0.04 12.6 90 0.81 0.03	0.11 14.9 120 0.83 0.05	0.20 17.3 240 0.85 0.20	0.30 20.0 400 0.88 0.45	0.44 24.1 800 0.92 0.90	31.2	0.76 41.7 40 0.50
To En	Residual Centroid Anisoplane Fedidual Atmospheric Disperi Induced Plate Scale Deformat Residual Atmospheric Disperi Induced Plate Scale Deformat Residual Telescope Pointing I Total Tip/Tilk Error (Cover Covers 1.447 2.145 1.097	is) r K age deg m arcsec m/s	0.12 mm 1.20 mm 1.20 mm 1.21 m	15	nm	om con hele same and control street and control	I (%) 35 9 0.36 0 0.00 0 0 0 0 0 0 0	0.00 8.3 50 0.56 0.01 ted to the	0.00 10.1 70 0.75 0.02 Total Eff Magnitu 19.3 Values HO WFS	0.04 12.6 90 0.81 0.03 dective W	0.11 14.9 120 0.83 0.05	0.20 17.3 240 0.85 0.20	0.30 20.0 400 0.88 0.45	0.44 24.1 800 0.92 0.90	31.2	0.76 41.7 40 0.50
To En	Residual Centroid Anisoplana Residual Atmospheri Obsperi Induced Plate Scale Deformat Non-Common-Path Tip-Till Er Residual Telescope Pointing 1 Tenro Magn Total Tip/Till Error (tal Effective Wavefro squared Energy / Coverage / Coverage / Corresponding Sky sumptions / Paramet Atmospheric / Observing Paramet / Paramet / Atmospheric / Observing Paramet / Paramet / Observing P	islon ions or	axis) r K age deg m arcsec m/s m	0.12 mm 0.00 mm 1.60 mm 1.60 mm 1.21 mm 2.00 mm 4.9 mm Spax:	182 182	nm n	Om con helps 3.2 mass/Allocation 3.2 mass/Allocation Allocation Al	1 (%) 35 35 36 36 37 37 38 38 38 38 38 38	0.00 8.3 50 0.56 0.01 ted to the	0.00 10.1 70 0.75 0.02 Total Eff Magnitu 19.3 Values HO WFS	0.04 12.6 90 0.81 0.03	0.11 14.9 120 0.83 0.05	0.20 17.3 240 0.85 0.20	0.30 20.0 400 0.88 0.45	0.44 24.1 800 0.92 0.90	31.2	0.76 41.7 40 0.50
To En	Residual Centroid Anisoplane Fesidual Atmospheri Obsperi Induced Plate Scale Deformat Residual Atmospheri Obsperi Induced Plate Scale Deformat Residual Telescope Pointing 1 Total Tip/Titk Error (Total Tip/Titk Error (tal Effective Wavefro Lal Effective Wavefro Coverage Corresponding Sky sumptions / Paramet Atmospheric / Observing Fara Zenth Angle Industrial Parison Industrial Pari	islon ions or	is) r K age deg m arcsec m/s	0.12 mm 0.00 mm 1.60 mm 1.60 mm 1.21 mm 2.00 mm 4.9 mm Spax:	182 182 183 184 185	nm n	Om con helps 3.2 mass/Allocation 3.2 mass/Allocation Allocation FWHM (m FWHM (m Sequence O.C. Sequence	1 (%) 35 35 36 36 37 37 38 38 38 38 38 38	0.00 8.3 50 0.56 0.01 ted to the	0.00 10.1 70 0.75 0.02 Total Eff Magnitus 19.3 Values HO WFS Detected	0.04 12.6 90 0.81 0.03 ective W	0.11 14.9 120 0.83 0.05	0.20 17.3 240 0.85 0.20 17.2 948 57	0.30 20.0 400 0.88 0.45	0.44 24.1 800 0.92 0.90	31.2	0.76 41.7 40 0.50
To En	Residual Centroid Anisoplane Fesidual Atmospheri Obsperi Induced Plate Scale Deformat Residual Atmospheri Obsperi Induced Plate Scale Deformat Residual Telescope Pointing 1 Total Tip/Titk Error (Total Tip/Titk Error (tal Effective Wavefro Lal Effective Wavefro V Coverage Corresponding Sky sumptions / Paramet Atmospheric / Observing Para Zenth Angle Industrial Observing Para Detail Control Observing Para Wind Speed Wind Speed Outer Scale	contained to the contai	axis) r K age deg m arcsec m/s m	0.12 mm 0.00 mm 1.60 mm 1.60 mm 1.21 mm 2.00 mm 4.9 mm Spax:	182 183 184 185	nm n	3.0 m con likely a control of the co	1 (%) 35 35 36 36 37 37 38 38 38 38 38 38	0.00 8.3 50 0.56 0.01 ted to the	0.00 10.1 70 0.75 0.02 Total Eff Magnitude 19.3 Values HO WFS Detected	0.04 12.6 90 0.81 0.03 ective W	0.11 14.9 120 0.83 0.05 17.5	0.20 17.3 240 0.85 0.20	0.30 20.0 400 0.88 0.45	0.44 24.1 800 0.92 0.90	31.2	0.76 41.7 40 0.50
To En	Residual Centroid Anisoplane Residual Atmospheric Obsperi Induced Plate Scale Deformat Residual Atmospheric Obsperi Induced Plate Scale Deformat Residual Telescope Pointing I Total Tip/Tilk Error (One-ax One-ax	age deg m arcsec m/s m x 109 cm.	0.12 mm 0.00 mm 1.60 mm 1.60 mm 1.21 mm 2.00 mm 4.9 mm Spax:	182 183 184 185	nm n	Om con helps James Allocation Tip/Tit Str Total Streh FWHM (m neter (mas) 1: Square 0.0. Seeing-Limited 0.0. This fraction of sky ca 0.02 seeing-Limited 0.0. This fraction of sky ca 0.03 sH usin 1.7 e-rr 9 NO 0.029 SH usin 3.2 e-rr	1 (%) 35 9 0.36 6 0 0 0 0 0 0 0 0	0.00 8.3 50 0.56 0.01 ted to the	0.00 10.1 70 0.75 0.02 Total Eff Magnitude 19.3 Values HO WFS Detected	0.04 12.6 90 0.81 0.03 lective W	0.11 14.9 120 0.83 0.05 17.5	0.20 17.3 240 0.85 0.20 17.2 948 57	0.30 20.0 400 0.88 0.45	0.44 24.1 800 0.92 0.90	31.2	0.76 41.7 40 0.50
To En	Residual Centroid Anisoplane Fedidual Atmospheric Disperi Induced Plate Scale Deformat Residual Atmospheric Disperi Induced Plate Scale Deformat Residual Telescope Pointing I Total Tip/Tilt Error (Total Tip/Tilt Error (ion ions ions inter (one-ax in	axis) r K age deg m arcsec m/s x 109 cm	0.12 mm 0.00 mm 1.60 mm 1.60 mm 1.21 mm 2.00 mm 4.9 mm Spax:	as 0 6 6 6 6 6 6 6 6 6 6 6 6 6 7 9 1 6 9 1	nm n	Om con helps 3.2 mass/Allocation 3.2 mass/Allocation Allocation FWHM (m eter (mas) 15 Sequere 0.0. Sequere	1 (%) 35 9 0.36 6 0 0 0 0 0 0 0 0	0.00 8.3 50 0.56 0.01 ted to the	0.00 10.1 70 0.75 0.02 Total Eff Magnitude 19.3 Values HO WFS Detected	0.04 12.6 90 0.81 0.03 lective W	0.11 14.9 120 0.83 0.05 17.5	0.20 17.3 240 0.85 0.20 17.2 948 57	0.30 20.0 400 0.88 0.45	0.44 24.1 800 0.92 0.90	31.2	0.76 41.7 40 0.50
To En	Residual Centroid Anisoplana Residual Atmospheric Observinduced Plate Scale Deformat Plate Scale Deformation of Plate Scale Defor	COVER 30 A MOAD PINTERENT LEASE 1 A MOAD PINTE	age deg m arcsec arcsec services servi	0.12 ms	as 91 182 182 183 91 182 182 183 184 186 186 30% 466 666 30% 466 676 676 676 677 677 677 67	nm n	Om con helps 3.2 mass/Allocation 3.2 mass/Allocation Allocation FWHM (m eter (mas) 15 Sequere 0.0. Sequere	1 (%) 35 9 0.36 6 0 0 0 0 0 0 0 0	0.00 8.3 50 0.56 0.01 ted to the	0.00 10.1 70 0.75 0.02 Total Eff Magnitude 19.3 Values HO WFS Detected	0.04 12.6 90 0.81 0.03 lective W	0.11 14.9 120 0.83 0.05 17.5	0.20 17.3 240 0.85 0.20 17.2 948 57	0.30 20.0 400 0.88 0.45	0.44 24.1 800 0.92 0.90	31.2	0.76 41.7 40 0.50
To En	Residual Centroid Anisoplane Fedidual Atmospheric Disperi Induced Plate Scale Deformat Residual Atmospheric Disperi Induced Plate Scale Deformat Residual Telescope Pointing I Total Tip/Tilt Error (Total Tip/Tilt Error (ion ions ions inter (one-ax in	r K Age deg m arssec m/s x x 109 cm	0.12 ms	18	nm n	Om con helps 3.2 mass/Allocation 3.2 mass/Allocation Allocation FWHM (m eter (mas) 15 Sequere 0.0. Sequere	1 (%) 35 9 0.36 6 0 0 0 0 0 0 0 0	0.00 8.3 50 0.56 0.01 ted to the	0.00 10.1 70 0.75 0.02 Total Eff Magnitude 19.3 Values HO WFS Detected	0.04 12.6 90 0.81 0.03 lective W	0.11 14.9 120 0.83 0.05 17.5	0.20 17.3 240 0.85 0.20 17.2 948 57	0.30 20.0 400 0.88 0.45	0.44 24.1 800 0.92 0.90	31.2	0.76 41.7 40 0.50

Table 6. Galaxy Assembly Case Wavefront and Ensquared Energy Budget

6.2 TT Sharpening Budget

KAON 721 includes an entirely separate wavefront error budget to describe the sharpening of TT NGS, which is a key input to understand the science path performance budget described in §6.1. An example of this for the Galaxy Assembly case is presented in Table 7.32

	LUWFS	Wavefront	⊏rror	buage	t Sum	mary		Version 2.	1					Scie					_
ode:		NGAO LGS									u'	g'	r'	i'	Z	Y	J	H	ŀ
trumer	t:	DAVINCI								λ (μm)	0.36	0.47	0.62	0.75	0.88	1.03	1.25	1.64	2
. Obse	rvation:	Galaxy Assembly								δλ (μm)	0.06	0.14	0.14	0.15	0.12	0.12	0.16	0.29	0.
		,								λ/D (mas)	7	10	13	15	18	21	26	34	4
OWE	C Lliab a	rder Errors (Mada	42.4	aracaa	off avi	Wavef	ront	Do	rameter				Streh	l Rati	o (%)			
OVVI	S migni-u	idei Ellois ((Wode)	42.4	aicsec	UII-axi	Error (rms)	га	ameter									
							,	, ,											_
	Atmospheric	Fitting Error					90	nm	30	Acts Across									
	Bandwidth E	rror					57	nm	54	Hz (-3db)									
	High-order M	easurement Error					79	nm	8.33	W									
	LGS Tomogr							nm		SCAO									
	Asterism De	ormation Error					16	nm	0.50	m LLT									
	Chromatic E	ror					1	nm		Upper limit									
	Dienareion D	isplacement Error					,	nm		Estimate for IR TT									
	Multispectral							nm		zen; flux-wght wav									
	Scintillation I			Н				nm		Scint index at 0.5um									
	WFS Scintill	ation Error					10	nm		Allocation									
					203	nm													
		e Static Telescope						nm	30	Acts Across									
		e Dynamic Telescop		ins				nm .											
		Zero-point Calibratio						nm		Allocation									
		S Zero-point Calibra						nm		Allocation									
		ator Zero-point Calib	ration Error					nm		Allocation									
	Stale Recons							nm		Allocation									
	Go-to Contro	Layer Focus Chang						nm nm		Allocation m/s Na layer vel									
	DM Finite St		е					nm		um P-P MEMS strok				-					
	DM Hysteres							nm	from LAO	UIII F-F MEMO SHOR	-								
	High-Order A							nm		Subaps									
	DM Drive Did							nm		bits									
	Uncorrectabl	e AO System Aberr	ations				62	nm		Allocation									
		e Instrument Aberra	tions				30	nm (DAVINCI	Indep PnS									
		t Misregistration						nm		Allocation									
	DM-to-lensle	Pupil Scale Error					25	nm		Allocation									
					124	nm													
		oplanatism Error						nm		arcsec									
	HO wavefror	t Error Margin					45	nm		Allocation									
	Total Hi	h Order Wa	vefront	Frror	238	nm	238	nm	High C	rder Strehl	0.00	0.00	0.00	0.02	0.05	0.12	0.23	0.42	٥
							200		g c		0.00	0.00	0.00	0.02	0.00	0.12	U.LU	0.12	٠.
ssur	nptions /	Parameters																	
	Atmosphori	c / Observing Parar	notors			System D	arameters												
	Acmosphen	Zenith Angle		deg		System F	Effective PnS	GS radius		0.34	arcmin								
		rO On	0.147	m			PnS LGS Pov	wer		8.33	W								
		theta0_eff		arcsec			BTO Transmis			0.60			Derive	d Values					
		Wind Speed	10.97				PnS HO WFS		ion	0.38				PnS HO			1079	Hz	
		Outer Scale Sodium Abundanc	50	m x 10° cm			PnS WFS Typ				using	CCID74		Detected					
		Sodium Abundanc	3	x 10° cm			PnS WFS No		10	1.7 NO	e- ms			LGS retu	m per be	eacon	290	ph/cm	/se
	AO Modes o	f Operation						- IIII GIGGI	-0	140									
	AO INDUES O	Science AO Mode	MOAO																
		LOWFS AO Mode																	
							Max TT Rejec	tion Bandwi	dth	100	Hz								
						04	ion Parameter												
								o Timo		4000	000								
							Max Exposure	e Time		1800	sec								

Table 7. Galaxy Assembly TT Sharpening Budget

The TT sharpening budget includes many of the same error terms as the science path error budget with several notable exceptions:

- As it represents the 'short exposure' wavefront error of the TT NGS, there are no tip-tilt error terms included here
- Focal anisoplanatism error in the NGAO case is calculated using a separate, single LGS beacon
 - The NGAO RTC architecture only supports independent patrolling LGS sharpening based on this one beacon; no advantage of fixed asterism tomography is assumed or allowed.
- The 'Science band' wavelength definitions in this table represent the sharpening of the TT NGS in different bands. The actual photometry of the sharpened TT star is based upon the selection of LO WFS pass-bands in the 'Input Summary' sheet.

The output of the TT sharpening budget becomes part of the science path residual tip-tilt error estimate (§6.1), as we take into account the near-IR Strehl ratio of the tip-tilt NGS when calculating the tip-tilt measurement error. The NGAO architectural choice of independently sharpening the tip-tilt NGS using the patrolling WFS / LO WFS DM subsystem significantly reduces the dependency of NGAO performance

on the particular vertical distribution of turbulence from night-to-night, though performance will vary as a function of overall seeing.

6.3 TWFS Budget

During PD phase, NGAO TWFS budget development was begun, but not taken to its full implementation. Currently, KAON 721 estimates the focus term error that results from the SNR and bandwidth (incl. atmospheric averaging) behavior of the (typically) off-axis visible TWFS star. The initial implementation is summarized in Table 8

Truth Wavefront	Sensor High-ord	er Errors	Wavef Error (Wavefront I Focus Only		Parameter				
TWFS Measuren	nent Error		94	nm	19	nm	19.0	Mv			
	er Focus Change stal anisoplanatism Error		190	nm	30	nm	2.1	Integration	n time (secs)		
Time averaged fo	cus anisoplanatism Error				23	nm					
Total High	Order Wavefron	t Error	212	nm							
Residual N	la Layer Focus (hange			42	nm					
Sky Coverage	Galactic Lat.	60 deg									
Correspor	nding Sky Cover	age	30%								

Table 8. Galaxy Assembly TWFS Budget

The TWFS budget is used in the science path error budget (§6.1) to determine the final error due to vertical motion and redistribution of the mesospheric sodium layer. During the DD phase, we intend to further expand the fidelity and detail of the TWFS error budget to include additional low-order modes.

7 Galaxy Assembly Case Performance Sensitivities

7.1 LGS Performance vs. Seeing

NGAO will have to operate in a wide range of natural seeing conditions, so it is interesting to understand the sensitivity of performance to changes in the Fried parameter, r_0 . This is shown for the Galaxy Assembly Science Case in Figure 2.

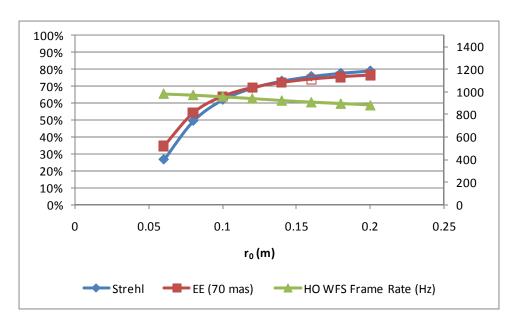


Figure 2. K-band performance for the Galaxy Assembly Science Case as a function of r₀ at 0.5 microns.

7.2 LGS Performance vs. Wind Speed

The 3-dimensional wind profile of the atmosphere above Mauna Kea can vary dramatically. Although our median a value for turbulence-weighted wind speed is 9.5 m/s (Appendix B), we would like to understand how performance degrades with increasing wind speed, and how it might improve under calmer conditions. Figure 3 demonstrates the sensitivity of performance, which is rather benign for the Galaxy Assembly Science Case, even for wind speeds treble our median assumption. As the wind speed is increased, the corresponding HO WFS frame rate increases (and recall, in the current KAON 721 model, this also simultaneously increases the HO WFS CCD pixel readout rate.) For a fixed pixel read rate, NGAO will have somewhat more performance sensitivity to high wind speeds, as the rejection bandwidth of atmospheric turbulence may not be able to keep up so optimally with increasing frame rate.

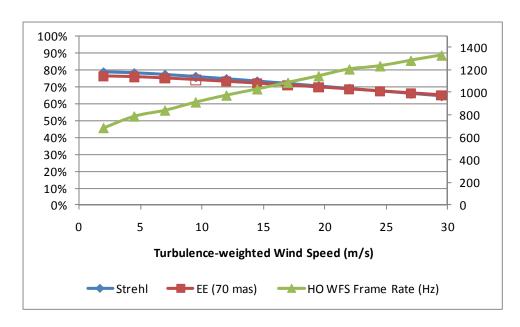


Figure 3. K-band performance for the Galaxy Assembly Science Case as a function of turbulence-weighted wind speed. The open marker indicates the median 9.5 m/s wind speed condition.

7.3 LGS Performance vs. Laser Return

Experience with the first-generation sodium D2-line resonant excitation LGS at Lick, Keck, and Palomar Observatories has shown that measured sodium photoflux can vary widely due to be sodium abundance fluctuations (see §7.10), but also because of variability in laser power and degradations in optical transmission in beam transfer uplink or AO system downlink optical systems.

We are interested in understanding the sensitivity of NGAO to variations in the expected sodium return photoflux. The results of two trade studies are shown in Figure 4 and Figure 5. In the first of these, we consider the impact of different levels of laser (spigot) power in absolute terms (assuming our usual "SOR-like" laser return) while in the second, we describe it as a percentage of the expected laser return (typically 55 photodetection events (PDE) / exposure time / subaperture, or 57 / 0.0011 / $(.1825^2)$ = 1.55×10^6 PDE/sec/m² or ~155 PDE/sec/cm², for each of the 12.5W (spigot) fixed asterism LGS¹⁹).

 $^{^{19}}$ We assume 75 ph/sec/cm²/W return from a 3 x 10^9 atoms/cm² sodium layer (itself from Denman's reported 150 ph/sec/cm² from Albuquerque with 4 x 10^9 atoms/cm² – see KAON 721), with 50W/4*.6 (BTO)*.88 (Atm) = 6.6 W per beacon delivered to mesosphere (495 ph/sec/cm² at mesosphere), followed by T=0.35, QE=0.85 on the downlink results in about 155 ph/sec/cm² detected by the WFS.

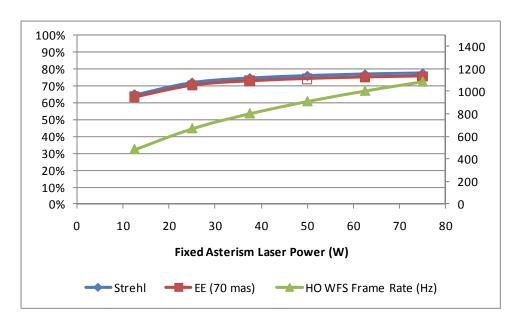


Figure 4 K-band wavefront error performance for the Galaxy Assembly Science Case as a function of fixed asterism laser power, holding patrolling asterism laser power constant at 25W (e.g. 3 x 8.33 W each.) The open marker indicates the baseline 50W of fixed asterism laser power (spigot).

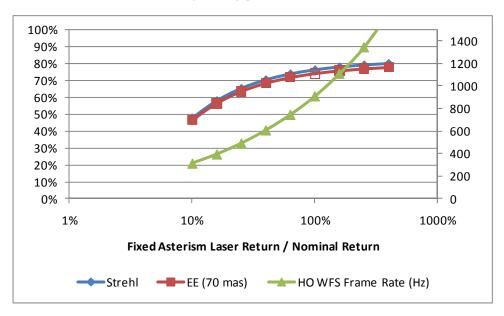


Figure 5. K-band wavefront error performance for the Galaxy Assembly Science Case as a function of fixed asterism laser return, relative to the expected return using our baseline conditions model (e.g. 3 x 10⁹ atoms/cm² sodium density, SOR-laser-like return, delivered and return transmission assumptions, etc.), holding patrolling asterism laser power constant at 25W (e.g. 3 x 8.33 W each.) The robustness of NGAO to less-than-expected laser return is clear for this science case.

7.4 LGS Performance vs. Sky Fraction

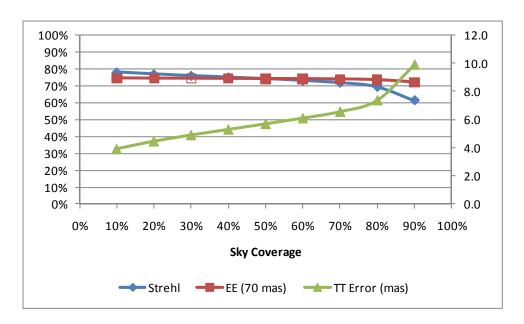


Figure 6. K-band wavefront error performance for the Galaxy Assembly Science Case as a function of sky coverage percentage, representing the likelihood of finding three NGS of sufficient brightness to achieve the indicated performance, within the FoR of the LO WFS. The residual TT error varies from about 4 mas to about 9 mas as the sky coverage fraction is increased.

7.5 LGS Performance vs. LO WFS Passband

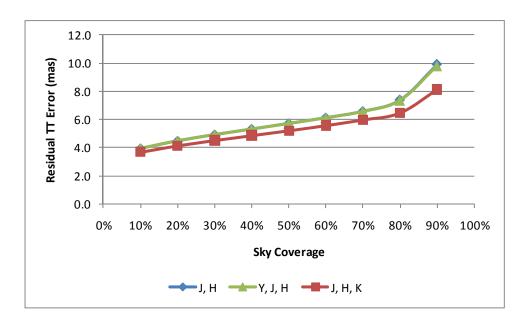


Figure 7. Residual TT error for the Galaxy Assembly Science Case as a function of sky coverage percentage, for three different choices of LO WFS passband. Inclusion of the design-complicating K-band is comparable to the uncertainty in our models, excepting perhaps at the highest sky fraction, where the advantage of including K-band would probably be real. Note, KAON 721 does not currently account for inter-filter-band sky emissions. Thus, these results should be considered for e.g. J + H, not the full range J through H. As such, the relative advantage of including K-band is probably overstated here.

Based on this marginal performance benefit of including K-band in the LO WFS passband shown in Figure 7, we have made the design decision to design for J+H alone, simplifying the LO WFS design, which would otherwise demand a cryogenic Lyot stop within each of the LO WFS cryostats.

7.6 LGS Performance vs. Spaxel Size

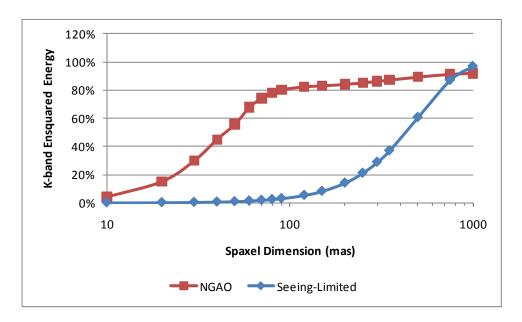


Figure 8. K-band Ensquared Energy vs. Spaxel Size for the Galaxy Assembly Science Case for NGAO correction and, for comparison, a seeing-limited PSF in median seeing conditions. (The relative transmission loss of NGAO compared to a Nasmyth-mounted seeing-limited instrument is not represented here – these curves reflect PSF shape only.)

7.7 LGS Performance vs. Number of LO WFS NGS

[XXX work to do – perform this trade study (will need to estimate the blind mode suppression from 1 or 2 NGS, not sure this is covered in KAON 429.]

7.8 NGS Performance vs. Natural Guide Star Brightness\

[XXX work to do – this should be straightforward for NGS science mode]

7.9 Interferometer Performance vs. Natural Guide Star Brightness

[XXX work to do – Do we need to define an interferometer science case to understand this? If this is simply bright NGS mode performance, does it differ from the previous section? If this is a LGS case, then we presumably want to vary a bright on-axis TT star? – Claire, Peter, can you help define this?]

7.10 Monte Carlo Error Budget Modeling Results

Although practically useful in understanding the sensitivities of NGAO performance to both seeing and turbulence-weighted wind speed variations, in practice NGAO will see on any given night seeing and wind speed values that are random variables drawn from some statistical distributions. In fact, there exists considerable detail on the statistics of these parameters at Mauna Kea. For our current purpose, however, an approximate form of these distributions will suffice to indicate the typical distribution of performance we might expect from a large number of observing nights. To quickly model this, we assume that both r_0 and wind speed are drawn from Gaussian probability distributions. Following the technique in 'Numerical Recipes in C, 2^{nd} Ed', page 289, we generated in Excel draws of the form:

	Mean	Standard Deviation, σ
r ₀ at 0.5 microns	0.16 m	0.025 m
Wind speed	9.5 m/s	4 m/s

where the distribution standard deviations, σ , are coarse estimates based on KAON 303. (A detailed determination of σ Is unlikely to improve these results, as I contend we are within the uncertainty level of the model²⁰.)

The results of 252 random draws (and frame rate optimizations) from this joint probably distribution is shown in Figure 9, for the case of mesospheric sodium abundance held constant at the below-median level of 3 \times 10 9 atoms/cm 2 . Note, unlike the current Keck 2 AO system, NGAO is seen to very rarely deliver performance less than about 60% K-band Strehl ratio. Moreover, NGAO is expected to deliver K-Strehls within a few percent of 78%, across varying different atmospheric conditions. This is a rather remarkable qualitative difference over current AO, one that we expect will dramatically improve both photometric accuracy and astrometric precision.

42

²⁰ For these Gaussian distributions, we also truncate the distribution to avoid negative values. Although not strictly valid, in practice it has little effect on the results shown here (e.g. we're not primarily interested in these rare outlier events.)

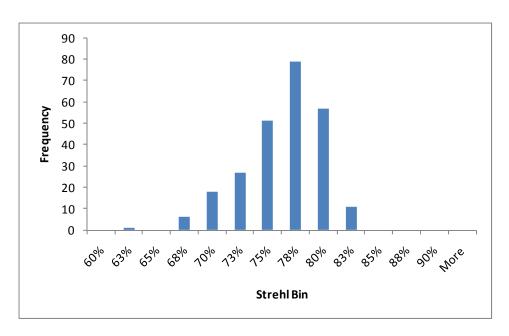


Figure 9. Predicted K-band performance distribution for NGAO based upon 252 r₀ and wind speed draws, holding sodium abundance constant at 3e9 atoms/cm^{2,} for the Galaxy Assembly Science Case.

Because sodium abundance can also vary, we repeated this random draw experiment, adding it as a third joint random variable:

	Mean	Standard Deviation, σ
Sodium abundance	3.6 x 10 ⁹ atoms/cm ²	1.0 x 10 ⁹ atoms/cm ²

where the mean is taken from KAON 416. We have estimated the standard deviation from Keck LGS experience which has shown that the large majority (\sim 90%) of time density is estimated to be between 1.6×10^9 and 5.6×10^9 atoms/cm² (e.g. +- 2σ). This result, for 394 random draws, is shown in Figure 10. Not surprisingly, this histogram is shifted to somewhat higher performance compared to our earlier submedian sodium abundance curve. Because sometimes the abundance can fall, even in conjunction with good seeing and slow winds, the (relatively) poorer performance tail is now seen to be extended, though still almost always above 60% K-Strehl.

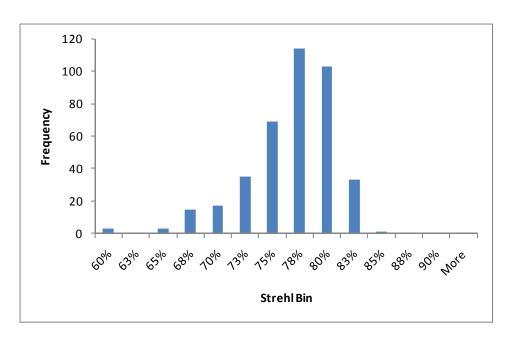


Figure 10. Predicted K-band performance distribution for NGAO based upon 394 r₀, wind speed, and sodium abundance draws for the Galaxy Assembly Science Case.

To better appreciate the advantage of NGAO over current Keck 2 AO, we repeated the experiment described in Figure 10 with a mirror experiment, using the same parameter distributions, for our model of the Keck 2 AO system (previously validated as described in KAON 461). This result is shown in Figure 11. The first obvious benefit of NGAO is an approximately 3x improvement in K-band Strehl ratio over current Keck 2 AO, which direct improves telescope sensitivity for background-limited imaging. The difference in results distribution width is also quite striking, particularly if one considers the *relative* stability of the predicted results, with NGAO showing perhaps +- 4% variation around a 78% peak (+- 5% relative), while the Keck 2 AO result shows +- 10% around a 30% median, which is more like +- 33% relative variation.

The skewness of these distributions is also worth noting. For Keck 2 AO, the longer tail is toward good performance, so it is more likely that an observer will have heard of someone at some time having a particularly good result with Keck 2 AO, but the median performance, they're average experience with AO, tends to fall short of this. For NGAO, on the other hand, we expect the user experience to be more often consistent with the maximum capability of the system. The occasional unfortunate night for an NGAO observer will doubtless draw heartfelt condolences from their colleagues.

More practically, NGAO instrument development will also benefit from this tendency to deliver more predictable image quality, perhaps by reducing the number of configurations, such as plate scales, that is typically necessary when delivered performance is widely variable.

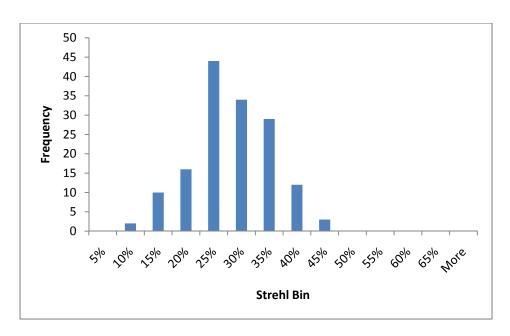


Figure 11 Predicted K-band performance distribution for the current Keck 2 AO system based upon 150 r_0 , wind speed, and sodium abundance draws for the Galaxy Assembly Science Case. Note the change in Strehl Bin scale compared to the NGAO predictions.

7.11 LAOS Simulation Modeling Results

[XXX – this section is unlikely to survive; we haven't done these sims and it's unclear if we will have the time – Chris, want to comment?]

8 NGAO Science Cases Performance Summaries

KAON 721 captures the observing scenario information relevant to each of the NGAO science cases. Evaluation of the NGAO performance for each case has been automated using VBA for Applications scripts that:

- For each LGS and NGS observing scenario
 - Optimize HO WFS frame rate, TT WFS frame rate, off-axis NGS LO WFS frame rate, and TWFS frame rate; consistent with the requirements for sky coverage fraction (all as appropriate to that configuration).
 - Capture the summary error budget as shown on the 'Optim' worksheet into a new "Output" file independent of KAON 721 (copy by value, essentially).

8.1 Performance Summary

The performance summary of the NGAO PD phase design for all these Science Cases is summarized in Table 9.

KAON 721 Case	Science Case	High- order RMS Wavefront Error (nm)	RMS TT Error (mas)	Effective Total RMS Wavefront Error (nm)	Ensquared Energy within a 70 mas spaxel	Observing Passband
1	Galaxy Assembly	160	4.9	182	75%	К
2	Nearby AGN	161	4.8	179	29%	Z
3	Galactic Center	186	2.2	190	60%	Т
4	Galactic Center Spectra	189	2.4	194	59%	Н
5	Exo-planets	158	7.8	207	69%	Н
6	Minor Planets	159	5.0	179	30%	Z
7	lo	116	2.1	119	54%	Z
8	QSO Host Galaxies	154	2.3	157	71%	Н
9	Gravitational Lensing	171	5.0	192	65%	Н
10	Astrometry Science	171	4.7	189	65%	Н
11	Transients	156	2.6	162	31%	Z
12	Resolved Stellar Populations	215	6.4	236	6%	l'
13	Debris Disks and YSOs	157	3.1	165	19%	l'
14	Gas Giant Planets	169	3.5	180	73%	К
15	Ice Giant Planets	190	4.4	204	59%	Н

Table 9. Summary of predicted wavefront error performance for all NGAO science cases.

[XXX – work to do: need more interpretation of these results. Is this good or bad? Will NGAO meet the science objectives we set out?]

8.2 Science Path WFE using NGS WFS in TWFS mode

There are three NGAO modes of operation that require use of the visible-light NGS WFS in a 5x5 subaperture pupil sampling mode:

- Pupil Fixed mode operation (typical of exoplanet searches and characterization),
- Image Fixed mode when the availability of field NGS for LO WFS sensing of TT and blind mode sensing is not favorable compared to use of the science target itself for both TT and blind mode information, and
- Interferometer mode which needs to use NGS WFS for both TT and TWFS functionality. In this mode, NGAO would often use an NGS other than the on-axis science object.

In theory, it may be possible to combine information from the NGS WFS in TWFS mode with information from the LO WFS, to further optimize performance, but this will not be investigated here. Instead, we would like to understand the TT performance (only) of the NGS WFS in TWFS mode, as a function of science target brightness, and more specifically we're interested in knowing how the red-wavelength NGS WFS cutoff choice affects performance in the NGS WFS TWFS mode. The results of just such a trade study are shown in Figure 12.

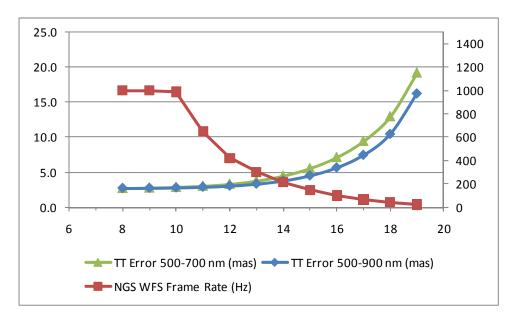


Figure 12. Performance of the NGAO NGS WFS for TT measurement, when operating in 5x5 subaperture TWFS mode, for NGS passband approximately 500 – 900 nm, compared to passband approximately 500 – 700 nm. These curves are optimized for best TT performance, and do not include the degradation of TWFS sensing of the laser tomography blind modes as the NGS WFS frame rate is slowed. The indicated optimal NGS WFS frame rate corresponds to the 500 – 900 nm passband case.

In generating Figure 12, we assume that the NGS WFS frame rate is optimized to provide the best TT measurement, without regard to the potential impact on its ability to accurately measure the laser tomography blind modes. If we assume that the need for accurate blind mode measurement requires us to operate the NGS WFS in TWFS mode no slower than 200 Hz (an admittedly arbitrary number), the quality of NGS WFS TT sensing breaks down considerable faster, as shown in Figure 13.

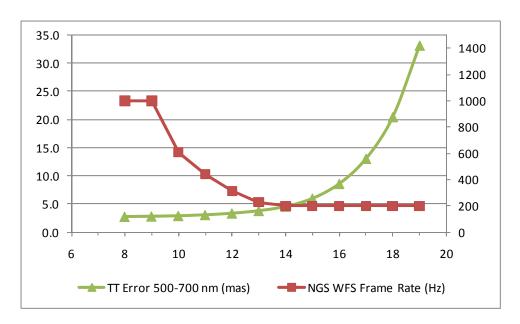
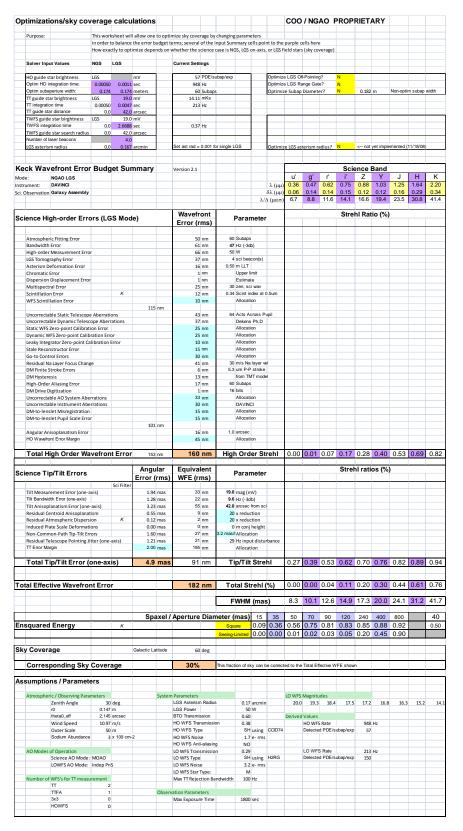


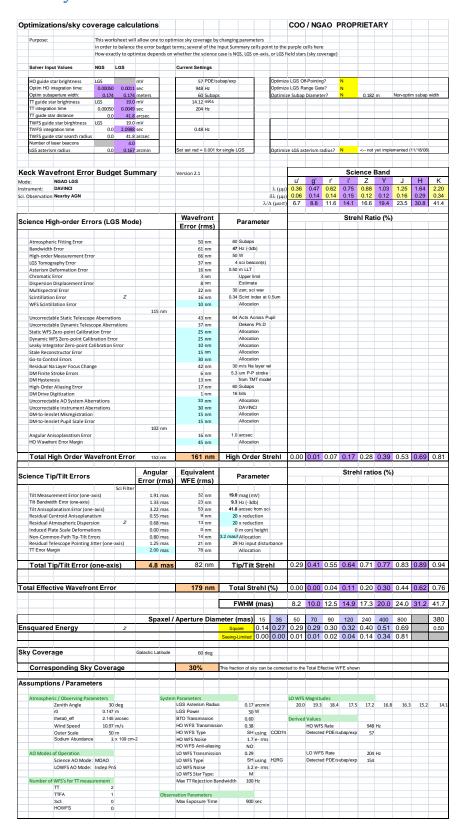
Figure 13 Performance of the NGAO NGS WFS for TT measurement, when operating in 5x5 subaperture TWFS mode, for NGS passband approximately 500 – 700 nm, with a minimum frame rate limit of 200 Hz. This may be more indicative of TT operation when the NGS WFS is required to read out relatively fast to maintain good blind mode measurement.

Appendix A: Key Science Case Detailed Error Budgets

Galaxy Assembly



Nearby AGN



Galactic Center Imaging

ptimizations/sky cov											coo	, 140	AU 1	KOF	XIE 17				
Purpose:	This work in order t	ksheet wil to balance	I allow one the error b	to optir udget te	mize sky cove erms; several	rage by of the	changing	parame	eters ells poir	nt to the	purple o	ells here	2						
					whether the s														
Solver Input Values	NGS	LGS			Current Sett	ings													
HO guide star brightness	LGS		mV		48	PDF/s	ubap/exp			Ontimiza	LGS Of	-Pointing	12	N					
Optim HO integration time:	0.00050		sec		1023	Hz				Optimiz	LGS Ra	nge Gat	e?	N					
Optim subaperture width: TT guide star brightness	0.174 LGS		meters mV			Subap	S			Optimiz	e Subap	Diamete	er?	N	0.182	m	Non-optir	m subap v	width
TT integration time	0.00050				2000	Hz													
TT guide star distance TWFS guide star birghtness	LGS		arcsec mV																
TWFS integration time	0.0	0.0093	sec		107.26	Hz													
TWFS guide star search radius Number of laser beacons	0.0	5.6 4.0	arcsec			_					_								
LGS asterism radius	0.0		arcmin		Set ast rad =	0.001 f	or single L	.GS		Optimiz	e LGS ast	terism ra	adius?	N	< not	yet imple	mented (11/18/08)	
eck Wavefront Error	Budg	et Sur	mmary		Version 2.1									Scie	ence l	Band			
ode: NGAO LGS											u'	g'	ď	i'	Z	Υ	J	Н	K
trument: DAVINCI . Observation Gal Cen										λ (μμ) δλ (μμ)	0.36	0.47	0.62	0.75 0.15	0.88	1.03 0.12	1.25 0.16	1.64 0.29	0.3
Observation our our										ι (μασ) (μασ)	6.7		11.6	14.1	16.6			30.8	41.
					Wavefr	ont								Strol	al Dat	io (%)			
cience High-order Erro	ors (LG	S Mod	ie)		Error (r		1	Parar	neter					Sire	II Kal	10 (%)			
Atmospheric Fitting Error Bandwidth Error						nm		Subaps Hz (-3d											
High-order Measurement Error	ır				79	nm	50	W											
LGS Tomography Error						nm		sci bea	con(s)										
Asterism Deformation Error Chromatic Error						nm nm		m LLT Upper li	mit										
Dispersion Displacement Error					6	nm		Estimat	e										
Multispectral Error Scintillation Error		Н				nm		zen; sc Scint in		.5um									
WFS Scintillation Error		Ė				nm		Allocati											
Uncorrectable Static Telescope	e Aherrati	ons	153	nm	42	nm	64	Acts Ac	ross P	ıpil									
Uncorrectable Dynamic Telesco	ope Aberr				34	nm		Dekens	Ph.D										
Static WFS Zero-point Calibrati Dynamic WFS Zero-point Calib	ion Error				25	nm		Allocati											
Dynamic WFS Zero-point Calib Leaky Integrator Zero-point Ca	auon Erro	Error				nm nm		Allocati											
Stale Reconstructor Error					15	nm		Allocati	on										
Go-to Control Errors Residual Na Layer Focus Chang	ge					nm		Allocati m/s Na		1									
DM Finite Stroke Errors					5	nm	5.3	um P-P	stroke										
DM Hysteresis High-Order Aliasing Error						nm		from TM Subaps											
DM Drive Digitization					1	nm	16	bits											
Uncorrectable AO System Aber						nm		Allocati											
Uncorrectable Instrument Abe DM-to-lenslet Misregistration						nm		Allocati											
DM-to-lenslet Pupil Scale Error					15	nm		Allocati	on										
Angular Anisoplanatism Error			92	nm	24	nm	1.0	arcsec											
HO Wavefront Error Margin						nm		Allocati	on										
Total High Order Wa	vefron	t Error	170	nm	186	nm	High	n Ord	or Sti	rehl	0.00	0.00	0.03	n na	0.17	0.28	0.42	0.60	0.7
rotarriigii Oraci wa	VCIIOII	LLIIOI	175		100		iligi	. 0. 0	C. O.	CIII	0.00	0.00	0.00	0.03	0.17	0.20	0.72	0.00	0.7
cience Tip/Tilt Errors			Angu		Equiva			Paran	neter					Strel	ıl rati	os (%))		
- 		Sci Filter	Error (rms)	WFE (ri	ns)													
Tilt Measurement Error (one-a				mas		nm		mag (m											
Tilt Bandwidth Error (one-axis)				mas		nm	50.0	Hz (-3d	b)										
									from sci										
Tilt Anisoplanatism Error (one- Residual Centroid Anisoplanat			0.64		11			x reduc	from sci tion										
Tilt Anisoplanatism Error (one- Residual Centroid Anisoplanat Residual Atmospheric Dispersi	ion	Н	0.53	mas	11 10	nm	20	x reduc	from sci tion tion										
Tilt Anisoplanatism Error (one- Residual Centroid Anisoplanat Residual Atmospheric Dispersi Induced Plate Scale Deformati	ion ions	Н	0.53	mas	11 10 0	nm	20 0	x reduc x reduc m conj	from sci tion tion height										
Tilt Anisoplanatism Error (one- Residual Centroid Anisoplanat Residual Atmospheric Dispersi Induced Plate Scale Deformati Non-Common-Path Tip-Tilt Err Residual Telescope Pointing Ji	ion ions rors		0.53 0.00 0.01 0.23	mas mas mas mas	11 10 0 0 4	nm nm nm nm	20 0 3.2 mas/l 29	x reduc x reduc m conj Allocat Hz inpu	from sci tion tion height ion it distur	bance									
Tilt Anisoplanatism Error (one- Residual Centroid Anisoplanat Residual Atmospheric Dispersi Induced Plate Scale Deformati- Non-Common-Path Tip-Tilt Err	ion ions rors		0.53 0.00 0.01 0.23	mas mas mas	11 10 0 0 4	nm nm nm	20 0 3.2 mas/l 29	x reduc x reduc m conj Allocat	from sci tion tion height ion it distur	bance									
Tilt Anisoplanatism Error (one- Residual Centroid Anisoplanat Residual Atmospheric Dispersi Induced Plate Scale Deformati Non-Common-Path Tip-Tilt Err Residual Telescope Pointing Ji	ion ions rors itter (one-	-axis)	0.53 0.00 0.01 0.23 2.00	mas mas mas mas	11 10 0 0 4 145	nm nm nm nm	20 0 3.2 mas/l 29	x reduc x reduc m conj Allocat Hz inpu	from sci tion tion height ion it distur		0.64	0.76	0.84	0.89	0.92	0.94	0.96	0.97	0.9
Tilt Anisoplanatism Error (one- Residual Centroid Anisoplanat Residual Atmospheric Dispersi Induced Plate Scale Deformati Non-Common-Path Tip-Tilt Err Residual Telescope Pointing Ji TT Error Margin	ion ions rors itter (one-	-axis)	0.53 0.00 0.01 0.23 2.00	mas mas mas mas mas	11 10 0 0 4 145	nm nm nm nm nm	20 0 3.2 mas/l 29	x reduc x reduc m conj Allocat Hz inpu Allocat	from sci tion tion height ion it distur		0.64	0.76	0.84	0.89	0.92	0.94	0.96	0.97	0.9
Tilt Anisoplanatism Error (one- Residual Centroid Anisoplanat Residual Atmospheric Dispersi Induced Plate Scale Deformati Non-Common-Path Tja-Tilte Error Residual Telescope Pointing Ji TT Error Margin Total Tip/Tilt Error (c	ion ions rors itter (one-	-axis)	0.53 0.00 0.01 0.23 2.00	mas mas mas mas mas	11 10 0 0 4 145	nm nm nm nm nm	20 0 3.2 mas/l 29	x reduc x reduc m conj Allocat Hz inpu Allocat	from sci tion ttion height ion it distur ion	nl				0.89					
Tilt Anisoplanatism Error (one- Residual Centroid Anisoplanat Residual Atmospheric Dispersi Induced Plate Scale Deformati Non-Common-Path Tja-Tilte Error Residual Telescope Pointing Ji TT Error Margin Total Tip/Tilt Error (c	ion ions rors itter (one-	-axis)	0.53 0.00 0.01 0.23 2.00	mas mas mas mas mas	11 10 0 0 4 145	nm nm nm nm nm	20 0 3.2 mas/l 29	x reduc x reduc m conj Allocat Hz inpu Allocat p/Tilt	trom sci tion tion height ion at distur ion Strel	nl %)		0.00	0.02	0.08	0.16	0.26	0.40	0.59	0.7
Tilt Anisoplanatism Error (one- Residual Centroid Anisoplanat Residual Atmospheric Dispersi Induced Plate Scale Deformati Non-Common-Path Tip-Tilt Err Residual Telescope Pointing Ji TT Error Margin	ion ions rors itter (one-	-axis)	0.53 0.00 0.01 0.23 2.00	mas mas mas mas mas	11 10 0 0 4 145	nm nm nm nm nm	20 0 3.2 mas/l 29	x reduc x reduc m conj Allocat Hz inpu Allocat p/T ilt	trom sci tion tion height ion at distur ion Strel	nl %)		0.00	0.02		0.16	0.26	0.40	0.59	0.9
Tilt Anisoplanatism Error (one- Residual Centroid Anisoplanat Residual Atmospheric Dispersi Induced Plate Scale Deformati Non-Common-Path Tja-Tilte Error Residual Telescope Pointing Ji TT Error Margin Total Tip/Tilt Error (c	ion ions rors itter (one-	-axis)	0.53 0.00 0.01 0.23 2.00	mas mas mas mas mas mas	11 10 0 0 4 145 42	nm nm nm nm nm nm	20 0 3.2 mas/l 29 Ti	x reduc x reduc m conj Allocat Hz inpu Allocat p/Tilt tal St	trom sci tion tion height ion at distur ion Strel	nl %)		0.00	0.02	0.08	0.16	0.26	0.40	0.59	0.7
Tilt Anisoplanatism Error (one- Residual Centrol Anisoplanat Residual Almospharic Dispersion Residual Almospharic Dispersion Residual Telegace Deformation Non-Common-Path Tip-Tilt Err Residual Telescope Pointing Ji TT Ernor Margin Total Tip/Tilt Error (c)	ion ions rors itter (one-	-axis)	0.53 0.00 0.01 0.23 2.00	mas mas mas mas mas mas	11 10 0 0 4 145	nm nm nm nm nm nm	20 0 3.2 mas/l 29 Ti	x reduc x reduc m conj Allocat Hz inpu Allocat p/Tilt tal St	from sci tion tion height ion it distur ion Strel	nl %)	0.00 7.1	9.1	0.02	0.08	0.16	0.26	0.40	0.59	0.7
Tilt Anisoplanatism Error (one- Residual Centroid Anisoplanat Residual Atmospheric Dispersi Induced Plate Scale Deformati Non-Common-Path Tja-Tilte Error Residual Telescope Pointing Ji TT Error Margin Total Tip/Tilt Error (c	ion ions rors itter (one-	axis)	0.53 0.00 0.01 0.23 2.00	mas mas mas mas mas mas	11 10 0 0 4 145 42	nm nm nm nm nm nm	20 0 3.2 mas/l 29 Ti	x reduc x reduc m conj Allocat Hz inpu Allocat p/Tilt tal St WHM mas)	from sci ttion ttion height ion it distur- ion Strel (mas	%) 35	0.00 7.1 50	0.00 9.1 70 0.60	0.02 11.8 90 0.61	0.08 14.3	0.16 16.8 240 0.67	0.26 19.6 400 0.73	0.40 23.7 800 0.84	0.59	0.7
Tilt Anisoplanatism Error (one- Residual Centrol Anisoplanat Residual Almospheric Dispersi Residual Almospheric Dispersi Residual Almospheric Dispersi Residual Telescope Pointing II Till Error Residual Telescope Pointing II Total Tip/Tilt Error (or tal Effective Wavefror	ion ions rors itter (one-	axis)	0.53 0.000 0.01 0.23 2.00 2.22	mas mas mas mas mas mas	111 100 0 0 4 4 145 42 190	nm nm nm nm nm	20 0 3.2 mas/l 29 Ti To F neter (x reduc x reduc m conj Allocat Hz inpu Allocat p/Tilt tal St WHM mas)	from sci tion tion height ion t distur ion Strel (mas 15 0.11	%) 35 0.39	0.00 7.1 50 0.53	0.00 9.1 70 0.60	0.02 11.8 90 0.61	0.08 14.3 120 0.62	0.16 16.8 240 0.67	0.26 19.6 400 0.73	0.40 23.7 800 0.84	0.59	0.7 41
Till Anisoplanatism Error (one- Residual Cartorid Anisoplanati Residual Atmospheric Disparsi Residual Atmospheric Disparsi Residual Atmospheric Disparsi Non-Common-Path Tip-Till Err Residual Telescope Pointing II TE inno Margin Total Tip/Till Error (cr	ion ions rors itter (one-	axis)	0.53 0.00 0.01 0.23 2.00	mas mas mas mas mas mas	111 100 0 0 4 4 145 42 190	nm nm nm nm nm nm	20 0 3.2 mas/l 29 Ti To F neter (x reduc x reduc m conj Allocat Hz inpu Allocat p/Tilt tal St WHM mas)	from sci tion tion height ion t distur ion Strel (mas 15 0.11	%) 35 0.39	0.00 7.1 50 0.53	0.00 9.1 70 0.60	0.02 11.8 90 0.61	0.08 14.3 120 0.62	0.16 16.8 240 0.67	0.26 19.6 400 0.73	0.40 23.7 800 0.84	0.59	0.7 41
Till Anisoplanatism Error (one- Residual Cartorid Anisoplanati Residual Atmospheric Disparsi Residual Atmospheric Disparsi Residual Atmospheric Disparsi Non-Common-Path Tip-Till Err Residual Telescope Pointing II TE inno Margin Total Tip/Till Error (cr	ion ions rors itter (one- one-ax nt Erro	is)	0.53 0.000 0.01 0.23 2.00 2.22	mas mas mas mas mas mas	111 100 0 0 4 4 145 42 190	nm nm nm nm nm	20 0 3.2 mas/l/ 29 Ti To F	x reduce x reduce m conj Allocat Hz inpu Allocat tal St WHM mas)	strell ((mas 15 0.11 0.00	%) 35 0.39 0.00	0.00 7.1 50 0.53 0.01	0.00 9.1 70 0.60 0.02	0.02 11.8 90 0.61 0.03	0.08 14.3 120 0.62	0.16 16.8 240 0.67 0.18	0.26 19.6 400 0.73	0.40 23.7 800 0.84	0.59	0.7 41
Till Anisoplanatism Error (one- Residual Centrol Anisoplanat Residual Atmospheric Dispersi Residual Atmospheric Dispersi Residual Atmospheric Dispersi Non-Common-Path Tip-Till Err Residual Telescope Pointing Ji TT Error Margin Total Tip/Tilt Error (c tal Effective Wavefror squared Energy y Coverage Corresponding Sky	ions lons rors there (one-axions Error) Covers	is)	0.53 0.000 0.01 0.23 2.00 2.22	mas mas mas mas mas mas	111 100 0 0 0 4 145 42 190 Aperture	nm nm nm nm nm	20 0 3.2 mas/l/ 29 Ti To F	x reduce x reduce m conj Allocat Hz inpu Allocat tal St WHM mas)	strell ((mas 15 0.11 0.00	%) 35 0.39 0.00	0.00 7.1 50 0.53 0.01	0.00 9.1 70 0.60 0.02	0.02 11.8 90 0.61 0.03	0.08 14.3 120 0.62 0.05	0.16 16.8 240 0.67 0.18	0.26 19.6 400 0.73	0.40 23.7 800 0.84	0.59	0.7 41
Till Anisoplanatism Error (one- Residual Centrol Anisoplanat Residual Armospheric Dispersi Residual Armospheric Dispersi Residual Armospheric Dispersi Non-Common-Path Tip-Till Err Residual Telescope Pointing Ji TT Error Margin Total Tip/Tilt Error (c tall Effective Wavefror esquared Energy y Coverage Corresponding Sky	ions lons rors there (one-axions Error) Covers	is)	0.53 0.000 0.01 0.23 2.00 2.22	mas mas mas mas mas mas	111 100 0 0 0 4 145 42 190 Aperture	nm nm nm nm nm	20 0 3.2 mas/l/ 29 Ti To F	x reduce x reduce m conj Allocat Hz inpu Allocat tal St WHM mas)	strell ((mas 15 0.11 0.00	%) 35 0.39 0.00	0.00 7.1 50 0.53 0.01	0.00 9.1 70 0.60 0.02	0.02 11.8 90 0.61 0.03	0.08 14.3 120 0.62 0.05	0.16 16.8 240 0.67 0.18	0.26 19.6 400 0.73	0.40 23.7 800 0.84	0.59	0.7 41
Till Anisoplandism Error (one- Residual Armospheric Dispersi Residual Armospheric Dispersi Moudeed Plate Scale Pedematin Non-Common-Path Tip-Title Err Residual Telescope Pointing III Total Tip/Till Error (or Total Tip/Till Error (or Stale Effective Wavefror	ion ions rors itter (one- one-axi one-axi Covera ers	is)	0.53 0.000 0.01 0.23 2.00 2.22	mas mas mas mas mas mas mas state mas system System	111 100 0 0 144 145 42 190 Aperture	nm nm nm nm nm nm nm	20 0 3.2 mas/n 29 Ti To F meter (i Squir Seeing-I	x reduc x reduc m conj M conj	rehl (mas 15 0.111 0.000	%) 35 0.39 0.00	0.00 7.1 50 0.53 0.01	0.00 9.1 70 0.60 0.02 Total Eff	0.02 11.8 90 0.61 0.03	0.08 14.3 120 0.62 0.05	0.16 16.8 240 0.67 0.18	0.26 19.6 400 0.73 0.42	0.40 23.7 800 0.84 0.88	30.9	0.7 41 44 0.5
Tilt Anisoplanatism Error (one- Residual Centrol Anisoplanat Residual Amospheric Dispersi Residual Atmospheric Dispersi Residual Atmospheric Dispersi Non-Common-Path Tip-Tilt Error Total Tip/Tilt Error (or Tip/Tilt E	ion ions rors itter (one- one-axi one-axi Covera ers	axis) is) H age	0.53 0.000 0.01 0.23 2.00 2.22	mas mas mas mas mas mas mas mas System	111 100 0 0 4 145 42 190 Aperture	nm nm nm nm nm nm	20 0 3.2 mas/n 29 Ti To F meter (i Squir Seeing-I	x reduc x reduc x reduc x reduc p/Tilt Hz inpu Allocat Hz inpu Hz inpu	rehl (mas 15 0.111 0.00	%) 35 0.39 0.00	0.00 7.1 50 0.53 0.01	0.00 9.1 70 0.60 0.02 Total Eff	0.02 11.8 90 0.61 0.03	0.08 14.3 120 0.62 0.05	0.16 16.8 240 0.67 0.18	0.26 19.6 400 0.73 0.42	0.40 23.7 800 0.84	30.9	0.7 41 44 0.5
Tilt Anisoplanatism Error (one Residual Centrol Anisoplanat Residual Armospheric Dispersi Residual Armospheric Dispersi Residual Armospheric Dispersi Non-Common-Path Tip-Tilte Error Tip Tribut Tip Tribut Tip Tribut Total Tip/Tilt Error (or	ion on one of the control of the con	axis) If H age deg m arcsec	0.53 0.000 0.01 0.23 2.00 2.22	mas mas mas mas mas mas mas mas System	111 100 0 0 145 42 190 Aperture 0 0 0% Parameters LGS Asterian LGS Power	nm nm nm nm nm nm	20 3.2 mas/s 29 Ti To F Seeing-1	x reduc x red	rehl (mass 15 0.11 0.00 arcmin W	%) 35 0.39 0.00	0.00 7.1 50 0.53 0.01 ed to the	0.00 9.1 70 0.60 0.02 Total Eff	0.02 111.8 90 0.61 0.03	0.08 14.3 120 0.62 0.05	0.16 16.8 240 0.67 0.18	0.26 19.6 400 0.73 0.42	0.40 23.7 800 0.84 0.88	30.9	0.7 41 44 0.5
Till Anisoplandism Error (one- Residual Centrol Anisoplandism Residual Almospheric Dispersion Residual Almospheric Dispersion Residual Almospheric Dispersion Non-Common-Path Tip-Title Error Residual Telescope Pointing Ji TT Ernor Margin Total Tip/Title Error (or tal Effective Wavefror Total Tip/Title Error (or tal Effective Wavefror Very Coverage Corresponding Sky sumptions / Paramete Atmospheric / Observing Para Atmospheric / Observing Para Design Angle On the dal. eff Wind Speed	Covera Covera 1.331 1.478	H Age deg m arcsec m/s	0.53 0.000 0.01 0.23 2.00 2.22	mas mas mas mas mas mas mas System	111 100 0 0 4 4 145 42 190 Aperture 0 0% Parameters LGS Asterian LGS Asterian BTO Transmith HO WFS Transmith HO WFS Transmith	nm	20 3.2 mas/s 29 Ti To F Seeing-1	x reduce x red	from sci from sci from sci from tition height ion Strel (mass 15 0.11 0.00 gran b arcmin W	35 0.39 0.00	0.00 7.1 50 0.53 0.01 ed to the	0.00 9.1 70 0.60 0.02 Total Eff 111.2 Values HO WFS	0.02 11.8 90 0.61 0.03 tective W	0.08 14.3 120 0.62 0.05	0.16 16.8 240 0.67 0.18	0.26 19.6 400 0.73 0.42	0.40 23.7 800 0.84 0.88	30.9	0.7 41 44 0.5
Tilt Anisoplanatism Error (one- seedsdual Centrol Anisoplanatism Residual Almospheric Dispersion Residual Almospheric Dispersion Non-Common-Path Tip-Tilt Error Tilt Error Margin Total Tip/Tilt Error (or Tip/Tilt E	covers Covers meters 50 0.123 1.331 1.478 50	axis) If H age deg m arcsec	0.53 0.000 0.01 0.23 2.000 2.2 Spa	mas mas mas mas mas mas s mas s s s s s	111 100 0 0 4 145 145 190 190 Aperture 0 0 Parameters LGS Asterian LGS Power BTO Transmit HO WFS Typ HO WFS Typ HO WFS Typ	nm n	20 3.2 mas/s 3.2 mas/s 29 Ti To F meter (t) Seeing-1	x reduc x red	rehl (mass 15 0.11 0.00 arcmin W	35 0.39 0.00	0.00 7.1 50 0.53 0.01 ed to the	0.00 9.1 70 0.60 0.02 Total Eff 111.2 Values HO WFS	0.02 11.8 90 0.61 0.03 tective W	0.08 14.3 120 0.62 0.05	0.16 16.8 240 0.67 0.18	0.26 19.6 400 0.73 0.42	0.40 23.7 800 0.84 0.88	30.9	0.7 41
Tilt Anisoplandism Error (one- seedsdual Centrol Anisoplandism Error (one- miduced Plate Scale Deformation Non-Common-Path Tip-Titte Error (of Tip Error Margin Total Tip/Tilt Error (of Total Effective Wavefror Total Effective Wavefror Total Tip/Tilt Error (of Total Tip/Tilt Error (of Total Tip/Tilt Error (of Total Effective Wavefror Total Tip/Tilt Error (of Tip/Tilt Error (o	covers Covers meters 50 0.123 1.331 1.478 50	H H age deg m arcsec m/s m	0.53 0.000 0.01 0.23 2.000 2.2 Spa	mas mas mas mas mas mas s mas s s s s s	111 100 0 0 4 145 145 142 190 Aperture 0 0 0% Parameters LGS Asterian LGS Power BTO Transmith HO WFS Tot HO WFS Typl HO WFS Typl HO WFS Typl HO WFS Nois	nm n	20 as/s as/s 29 Ti	x reduce x red	rehl (mass ton ton ton ton ton ton ton t	35 0.39 0.00	0.00 7.1 50 0.53 0.01 LO WFS 111.2 Derived	0.00 9.1 70 0.60 0.02 Total Eff Magnitut 111.2 Values HO WFS Detected	90 0.61 0.03 fective W	0.08 14.3 120 0.62 0.05	0.16 16.8 240 0.67 0.18	0.26 19.6 400 0.73 0.42	0.40 23.7 800 0.84 0.88	30.9	0.7 41 44 0.5
Till Anisoplanatism Error (one- Residual Centrol Anisoplanat Residual Almospheric Dispersi Residual Almospheric Dispersi Residual Almospheric Dispersi Residual Telace Deformation Non-Common-Path Tip-Till Error Residual Telescope Pointing Ji TT Ernor Margin Total Tip/Tilt Error (or Total Tip/Tilt Error	Covers Covers 1.331 14.78 3 3	H H age deg m arcsec m/s m	0.53 0.000 0.01 0.23 2.000 2.2 Spa	mas mas mas mas mas mas s mas System	111 100 0 0 4 4 145 42 190 190 Aperture 0 0 Parameters LGS Asterian LGS Power BTO Transmit HO WFS Total LOW SF Arma	nm n	20 as/s as/s 29 Ti	x reduce x red	intermental control of the control o	35 0.39 0.00	0.00 7.1 50 0.53 0.01 ed to the	0.00 9.1 70 0.60 0.02 Total Eff 111.2 Values HO WFS	90 0.61 0.03 fective W. W. S. Rate d PDE/s	0.08 14.3 120 0.62 0.05	0.16 16.8 240 0.67 0.18	0.26 19.6 400 0.73 0.42	0.40 23.7 800 0.84 0.88	30.9	0.7 41
Tilt Anisoplandism Error (one- seedsdual Centrol Anisoplandism Error (one- miduced Plate Scale Deformation Non-Common-Path Tip-Titte Error (of Tip Error Margin Total Tip/Tilt Error (of Total Effective Wavefror Total Effective Wavefror Total Tip/Tilt Error (of Total Tip/Tilt Error (of Total Tip/Tilt Error (of Total Effective Wavefror Total Tip/Tilt Error (of Tip/Tilt Error (o	one-axi meters 50 0.123 1.331 14.78 50 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.00	H age deg m m x 109 cm-	0.53 0.000 0.01 0.23 2.000 2.2 Spa	mas mas mas mas mas mas s mas s s s s s	111 100 0 0 14 145 145 190 190 190 190 190 190 190 190 190 190	nm n	20 as/s as/s 29 Ti	x reduc x red	rehl (mass ton ton ton ton ton ton ton t	35 0.39 0.00	0.00 7.1 50 0.53 0.01 ed to the	0.00 9.1 70 0.60 0.02 Total Eff 111.2 Values HO WFS	90 0.61 0.03 fective W. W. S. Rate d PDE/s	0.08 14.3 120 0.62 0.05	0.16 16.8 240 0.67 0.18	0.26 19.6 400 0.73 0.42	0.40 23.7 800 0.84 0.88	30.9	0.7 41 44 0.5
Tilt Anisoplandism Error (one- seedsdual Centrol Anisoplandism Error (one- miduced Plate Scale Deformation Non-Common-Path Tip-Titte Tresdual Telescape Pointing Ji TT E mor Margin Total Tip/Tilt Error (of Total Tip/Til	COVERS COVERS MOAD MOAD MOAD MOAD MOAD MOAD MOAD	H age deg m m x 109 cm-	0.53 0.000 0.01 0.23 2.000 2.2 Spa	mas mas mas mas mas mas s mas s s s s s	111 100 0 0 14 145 42 190 190 Aperture 0 0 % Aperture 1 Parameters LGS Asterian LGS Power BTO Transmis HO WFS Trait HO WFS MID LO WFS YEAU LO WFS YE	nm n	200 3.2 mas/s 29 Ti To F Seeing-1 This fract	x reduce x x x x x x x x x x x x x x x x x x x	from soic from soic from soic from soic from soic from soic from tition from tition from the fight from the fro	35 0.39 0.00	0.00 7.1 50 0.53 0.01 ed to the	0.00 9.1 70 0.60 0.02 Total Eff 111.2 Values HO WFS	90 0.61 0.03 fective W. W. S. Rate d PDE/s	0.08 14.3 120 0.62 0.05	0.16 16.8 240 0.67 0.18	0.26 19.6 400 0.73 0.42	0.40 23.7 800 0.84 0.88	30.9	0.7 41. 44 0.5
Tilt Anisoplanatism Error (one- seedsdual Centrol Anisoplanat Residual Almospheric Disperi Residual Almospheric Disperi Residual Almospheric Disperi Non-Common-Path Tip-Tilte Error (or TT E nor Margin Total Tip/Tilt Error (or Total Tip/Tilt Error (or Datal Effective Wavefror Residual Telescape Pointing Ji TT E nor Margin Total Tip/Tilt Error (or Datal Effective Wavefror Residual Telescape Pointing Ji Total Tip/Tilt Error (or Datal Effective Wavefror Residual Telescape Pointing Ji Parameter Corresponding Sky Sumptions / Parameter Atmospheric / Observing Parameter Joseph Goden Abudance Ad Modes Goperation Soloperation Ad Modes of Operation Oxides	COVERS COVERS MOAD MOAD MOAD MOAD MOAD MOAD MOAD	H H age deg m mssec m/s m/s x 109 cm-s	0.53 0.000 0.01 0.23 2.000 2.2 Spa	mas mas mas mas mas mas s mas s s s s s	111 100 0 0 14 145 145 190 190 190 190 190 190 190 190 190 190	nm n	200 3.2 mas/s 29 Ti To F Seeing-1 This fract	x reduc x red	from soic from soic from soic from soic from soic from soic from tition from tition from the fight from the fro	35 0.39 0.00	0.00 7.1 50 0.53 0.01 ed to the	0.00 9.1 70 0.60 0.02 Total Eff 111.2 Values HO WFS	90 0.61 0.03 fective W. W. S. Rate d PDE/s	0.08 14.3 120 0.62 0.05	0.16 16.8 240 0.67 0.18	0.26 19.6 400 0.73 0.42	0.40 23.7 800 0.84 0.88	30.9	0.7
Till Anisoplanatism Error (one- Residual Centrol Anisoplanatism Residual Anisoplanatism Residual Anisoplanatism Residual Anisoplanatism Residual Anisoplanatism Residual Telace Deformation Non-Common-Path Tip-Till Error Horgin Total Tip/Till Error (cross- Total Tip/Till Error (ion	H age deg marssec my/s my x 109 cm-	0.53 0.000 0.01 0.23 2.000 2.2 Spa	mas mas mas mas mas mas s mas s mas s s s	111 100 0 0 14 145 42 190 190 Aperture 0 0 % Aperture 1 Parameters LGS Asterian LGS Power BTO Transmis HO WFS Trait HO WFS MID LO WFS YEAU LO WFS YE	nm n	200 3.2 mas/s 29 Ti To F Seeing-1 This fract	x reduc x red	from soic from soic from soic from soic from soic from soic from tition from tition from the fight from the fro	35 0.39 0.00	0.00 7.1 50 0.53 0.01 ed to the	0.00 9.1 70 0.60 0.02 Total Eff 111.2 Values HO WFS	90 0.61 0.03 fective W. W. S. Rate d PDE/s	0.08 14.3 120 0.62 0.05	0.16 16.8 240 0.67 0.18	0.26 19.6 400 0.73 0.42	0.40 23.7 800 0.84 0.88	30.9	0.7 41 44 0.5

Galactic Center Spectra

ptimizations/sky cov						<u>.</u>					550	, 140		PROPI	AL 17	AIN I			
Purpose:	in order t	to balance	the error b	udget t	mize sky cove erms; several	of the	Input Sum	nmary ce	ells poir										
					whether the s														
Solver Input Values	NGS	LGS			Current Sett	ings													
HO guide star brightness	LGS		mV		48	PDE/s	ubap/exp				LGS Of			N					
Optim HO integration time: Optim subaperture width:	0.00050 0.174		sec meters		1023	Hz Subap					e LGS Ra e Subap			N N	0.182	m	Non-ontin	im subap v	width
TT guide star brightness	LGS	12.2	mV		4.60	mKs				Оринна	С Эцоцр	Diamet			0.102				
TT integration time TT guide star distance	0.00050		sec arcsec		2000	Hz													
TWFS guide star birghtness TWFS integration time	LGS 0.0		mV		106.84	U-													
TWFS guide star search radius	0.0	5.6	arcsec		100.64	112													
Number of laser beacons LGS asterism radius	0.0	4.0 0.167	arcmin		Set ast rad =	0.001 f	or single L	.GS		Ontimiz	e IGS ast	erism ra	adius?	N	< not	vet imple	mented ((11/18/08)	
EGS dateriali i dalida	0.0	0.107	urciiiii							Оринна	C 205 05		Julus.			,	,		
eck Wavefront Error	r Buda	et Su	mmarv		Version 2.1									Scie	ence l	Band			
nde: NGAO LGS	Juug	or our	u. y		VEISIONELL						u'	g'	ď	i'	Z	Υ	J	Н	K
trument: DAVINCI . Observation Gal Cen Spectra										λ (μμ) δλ (μμ)	0.36	0.47	0.62	0.75 0.15	0.88	1.03 0.12	1.25 0.16	1.64 0.29	0.3
. Observation our cen opecua										ι (μασ)	6.7		11.6	14.1	16.6			30.8	41.
					Wavefr	ont								Stre	hl Rat	io (%)			
cience High-order Erro	ors (LG	S Mod	le)		Error (r			Parar	neter					Ou o		.0 (70)			
Atananah saja Sitti sa Sasa						nm	60	Subaps											
Atmospheric Fitting Error Bandwidth Error					87	nm	51	Hz (-3d											
High-order Measurement Error LGS Tomography Error						nm nm	50 4	W sci bea	con(s)										
Asterism Deformation Error					25	nm	0.50	m LLT											
Chromatic Error Dispersion Displacement Error						nm nm		Upper li Estimat											
Multispectral Error					34	nm	50	zen; sc	wav	r									
Scintillation Error WFS Scintillation Error		Н				nm nm		Scint in Allocati		.oum									
Uncorrectable Static Telescope	a Abores	ons	153	nm		nm	6.4	Acts Ac	mee D	nil									
Uncorrectable Dynamic Telesco	ope Aberr				34	nm		Dekens	Ph.D	ų.									
Static WFS Zero-point Calibrati Dynamic WFS Zero-point Calib	ion Error					nm nm		Allocati											
Leaky Integrator Zero-point Ca	libration f	Error			10	nm		Allocati	on										
Stale Reconstructor Error Go-to Control Errors						nm nm		Allocati Allocati											
Residual Na Layer Focus Chang	3e				3	nm	30	m/s Na	layer ve	ı									
DM Finite Stroke Errors DM Hysteresis						nm nm		um P-P from TM		ı									
High-Order Aliasing Error						nm		Subaps bits											
DM Drive Digitization Uncorrectable AO System Aber	rrations					nm		Allocati											
Uncorrectable Instrument Abe DM-to-lenslet Misregistration						nm		DAVINO											
DM-to-lenslet Pupil Scale Error						nm		Allocati											
Angular Anisoplanatism Error			92	nm	44	nm	2.0	arcsec											
HO Wavefront Error Margin						nm		Allocati	on										
Total High Order Wa	vefron	t Error	179	nm	189	nm	High	n Ord	er Sti	rehl	0.00	0.00	0.02	0.08	0.16	0.27	0.41	0.59	0.7
cience Tip/Tilt Errors			Angu Error (Equiva WFE (r		1	Parar	neter					Strei	ii rati	os (%)	'		
		Sci Filter																	
Tilt Measurement Error (one-a Tilt Bandwidth Error (one-axis)				mas mas		nm		mag (m Hz (-3d											
Tilt Anisoplanatism Error (one- Residual Centroid Anisoplanat	-axis)			mas	9	nm	5.6	arocco											
	irm				11		20		from sci										
Residual Atmospheric Dispersi		Н		mas	11 10	nm		x reduc	tion										
Residual Atmospheric Dispersi Induced Plate Scale Deformati	ion ions	Н	0.53	mas	11 10 0	nm	20 0	x reduc x reduc m conj	tion tion height										
Residual Atmospheric Dispersi Induced Plate Scale Deformati Non-Common-Path Tip-Tilt Err Residual Telescope Pointing Ji	ion ions rors		0.53 0.00 0.80 0.23	mas mas mas	11 10 0 14 4	nm nm nm nm	20 0 3.2 mas/l 29	x reduc x reduc m conj Allocat Hz inpu	tion tion height ion it distur	bance									
Residual Atmospheric Dispersi Induced Plate Scale Deformati Non-Common-Path Tip-Tilt Err	ion ions rors		0.53 0.00 0.80 0.23	mas	11 10 0 14 4	nm nm nm	20 0 3.2 mas/l 29	x reduc x reduc m conj Allocat	tion tion height ion it distur	bance									
Residual Atmospheric Dispersi Induced Plate Scale Deformati Non-Common-Path Tip-Tilt Err Residual Telescope Pointing Ji	ion ions rors itter (one-	-axis)	0.53 0.00 0.80 0.23 2.00	mas mas mas	11 10 0 14 4 145	nm nm nm nm	20 0 3.2 mas/l 29	x reduc x reduc m conj Allocat Hz inpu	tion tion height ion it distur		0.61	0.73	0.83	0.88	0.91	0.93	0.95	0.97	0.9
Residual Atmospheric Dispersi Induced Plate Scale Deformati Non-Common-Path Tip-Tilt Err Residual Telescope Pointing Ji TT Error Margin	ion ions rors itter (one-	-axis)	0.53 0.00 0.80 0.23 2.00	mas mas mas mas	11 10 0 14 4 145	nm nm nm nm	20 0 3.2 mas/l 29	x reduc x reduc m conj Allocat Hz inpu Allocat	tion tion height ion it distur		0.61	0.73	0.83	0.88	0.91	0.93	0.95	0.97	0.9
Residual Atmospheric Dispersi Induced Plate Scale Deformati Non-Common-Path Tip-Tilt Err Residual Telescope Pointing Ji TT Error Margin	ion ions rors itter (one-	axis)	0.53 0.00 0.80 0.23 2.00	mas mas mas mas	11 10 0 14 4 145	nm nm nm nm nm	20 0 3.2 mas/l 29	x reduc x reduc m conj Allocat Hz inpu Allocat	tion tion height ion it distur ion	nl				0.88					0.9
Residual Atmospheric Dispersi Induced Plate Scale Deformatii Non-Common-Path Tip-Tilt Err Residual Telescope Pointing Ji TT Error Margin	ion ions rors itter (one-	axis)	0.53 0.00 0.80 0.23 2.00	mas mas mas mas	11 10 0 14 4 145	nm nm nm nm nm	20 0 3.2 mas/l 29	x reduc x reduc m conj Allocat Hz inpu Allocat p/T ilt	tion tion height ion it distur ion Strel	nl %)		0.00	0.02		0.15	0.25	0.39	0.57	0.7
Residual Atmospheric Dispersi Induced Plate Scale Deformatii Non-Common-Path Tip-Tilt Err Residual Telescope Pointing Ji TT Error Margin	ion ions rors itter (one-	axis)	0.53 0.00 0.80 0.23 2.00	mas mas mas mas	11 10 0 14 4 145 44 145	nm nm nm nm nm	20 0 3.2 mas/l 29 Ti	x reduc x reduc m conj Allocat Hz inpu Allocat p/Tilt tal St	ttion ttion height ion tt distur ion Strel rehl ((mas	nl %)	0.00 7.1	9.1	0.02	0.07	0.15	0.25	0.39	0.57	0.7
Residual Almospheric Dispersi Induced Plate Scale Deformation Non-Common-Path Tip-Title Err Residual Telescope Pointing Ji TT Enror Margin Total Tip/Title Error (c	ion ions rors itter (one-	axis)	0.53 0.00 0.80 0.23 2.00	mas mas mas mas	11 10 0 14 4 145	nm nm nm nm nm	20 0 3.2 mas/l 29 Ti	x reduc x reduc m conj Allocat Hz inpu Allocat p/Tilt tal St	ttion ttion height ion tt disturion Strel rehl (mas	%) 35	0.00 7.1 50	0.00 9.1	0.02	0.07 14.3	0.15 16.8 240	0.25 19.6 400	0.39	0.57	0.7
Residual Almospheric Dispersi Induced Plate Scale Deformation Non-Common-Path Tip-Title Err Residual Telescope Pointing Ji TT Enror Margin Total Tip/Title Error (c	ion ions rors itter (one-	axis)	0.53 0.00 0.80 0.23 2.00	mas mas mas mas	11 10 0 14 4 145 44 145	nm nm nm nm nm	20 0 3.2 mas/l 29 Ti To F neter (x reduc x reduc m conj Allocat Hz inpu Allocat p/Tilt tal St WHM mas)	ttion ttion height ion tt distur- ion Strel (mas 15 0.11	%) 35 0.39	0.00 7.1 50 0.52	0.00 9.1 70 0.59	0.02 11.8 90 0.60	0.07 14.3 120 0.61	0.15 16.8 240 0.66	0.25 19.6 400 0.73	0.39 23.7 800 0.84	0.57	0.7
Residual Almospheric Dispersi Induced Plate Scie Deformation Non-Common-Path Tip-Title Err Residual Telescope Pointing Ji TT Enor Margin Total Tip/Title Error (c)	ion ions rors itter (one-	axis)	0.53 0.000 0.80 0.23 2.00 2.44	mas mas mas mas	111 100 0 0 144 4 4 145 44 194	nm nm nm nm nm	20 0 3.2 mas/l 29 Ti	x reduc x reduc m conj Allocat Hz inpu Allocat p/Tilt tal St WHM mas)	ttion ttion height ion tt disturion Strel rehl (mas	%) 35	0.00 7.1 50	0.00 9.1 70 0.59	0.02 11.8 90 0.60	0.07 14.3	0.15 16.8 240 0.66	0.25 19.6 400 0.73	0.39 23.7 800 0.84	0.57	0.7
Residual Almospheric Dispersi Induced Plate Scie Deformation Non-Common-Path Tip-Title Err Residual Telescope Pointing Ji TT Enor Margin Total Tip/Title Error (c)	ion ions rors itter (one-	axis)	0.53 0.00 0.80 0.23 2.00	mas mas mas mas	111 100 0 0 144 4 4 145 44 194	nm nm nm nm nm	20 0 3.2 mas/l 29 Ti To F neter (x reduc x reduc m conj Allocat Hz inpu Allocat p/Tilt tal St WHM mas)	ttion ttion height ion tt distur- ion Strel (mas 15 0.11	%) 35 0.39	0.00 7.1 50 0.52	0.00 9.1 70 0.59	0.02 11.8 90 0.60	0.07 14.3 120 0.61	0.15 16.8 240 0.66	0.25 19.6 400 0.73	0.39 23.7 800 0.84	0.57	0.7
Residual Armospheric Dispersion Induced Plates Zace Deformation Mon-Common-Path Tip-Title Err Residual Telescope Pointing Jir TT Error Margin Total Tip/Title Error (c) tal Effective Wavefror	ion ions rors itter (one-	is)	0.53 0.000 0.80 0.23 2.00 2.44	mas mas mas mas	111 100 0 0 144 4 4 145 44 194	nm nm nm nm nm	20 0 3.2 mas/l/ 29 Ti To F	x reduce x reduce m conj Allocat Hz inpu Allocat tal St WHM mas)	Strel (mas 15 0.00	%) 35 0.39 0.00	0.00 7.1 50 0.52 0.01	0.00 9.1 70 0.59 0.02	0.02 11.8 90 0.60 0.03	0.07 14.3 120 0.61	0.15 16.8 240 0.66 0.18	0.25 19.6 400 0.73	0.39 23.7 800 0.84	0.57	0.7 41
Residual Almospheric Dispersi induced Plates Zoice Deformation Non-Common-Path Tip-Till Err Residual Telescope Pointing Ji TT Enror Margin Total Tip/Tilt Error (c	ions lons rors there (one-axions Error) Covers	is)	0.53 0.000 0.80 0.23 2.00 2.44	mas mas mas mas	111 100 014 44 145 44 145 44 194 Aperture	nm nm nm nm nm	20 0 3.2 mas/l/ 29 Ti To F	x reduce x reduce m conj Allocat Hz inpu Allocat tal St WHM mas)	Strel (mas 15 0.00	%) 35 0.39 0.00	0.00 7.1 50 0.52 0.01	0.00 9.1 70 0.59 0.02	0.02 11.8 90 0.60 0.03	0.07 14.3 120 0.61 0.05	0.15 16.8 240 0.66 0.18	0.25 19.6 400 0.73	0.39 23.7 800 0.84	0.57	0.7 41
Residual Almospheric Dispersi induced Plates Zoice Deformation Non-Common-Path Tip-Till Err Residual Telescope Pointing Ji TT Enror Margin Total Tip/Tilt Error (c	ions lons rors there (one-axions Error) Covers	is)	0.53 0.000 0.80 0.23 2.00 2.44	mas mas mas mas mas mas mas	111 100 0 144 4 4 4 145 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4	nm nm nm nm nm	20 0 3.2 mas/l/ 29 Ti To F	x reduce x reduce m conj Allocat Hz inpu Allocat tal St WHM mas)	Strel (mas 15 0.00	%) 35 0.39 0.00	0.00 7.1 50 0.52 0.01	0.00 9.1 70 0.59 0.02	0.02 11.8 90 0.60 0.03	0.07 14.3 120 0.61 0.05	0.15 16.8 240 0.66 0.18	0.25 19.6 400 0.73	0.39 23.7 800 0.84	0.57	0.7 41
Residual Almospheric Dispersion Induced Plate Scie Deformation Monce Common Path Tip-Title Err Residual Telescope Pointing Jit TE From Margin Total Tip/Title Error (c) tal Effective Wavefror squared Energy cy Coverage Corresponding Sky sumptions / Paramete Atmospheric / Observing Paramete Atmospheric / Observing Paramete	ion ions rors itter (one- one-axi one-axi Covera ers	is)	0.53 0.000 0.80 0.23 2.00 2.44	mas mas mas mas mas mas mas	111 100 0 144 445 444 194 Aperture	nm nm nm nm nm nm nm	20 0 3.2 mas/n 29 Ti To F meter (i Squir Seeing-I	x reduc x reduc m conj M conj	Strel (mass 15 0.11 0.00	%) 35 0.39 0.00	0.00 7.1 50 0.52 0.01	0.00 9.1 70 0.59 0.02 Total Ef	0.02 11.8 90 0.60 0.03	0.07 14.3 120 0.61 0.05	0.15 16.8 240 0.66 0.18	0.25 19.6 400 0.73 0.42	0.39 23.7 800 0.84 0.88	30.9	0.7 41 44 0.5
Residual Armospheric Dispersion Induced Plates Zue Deformation Non-Common-Path Tip-Title Err Residual Telescope Pointing Jit TT Ernor Margin Total Tip/Title Error (c tal Effective Wavefror squared Energy ty Coverage Corresponding Sky sumptions / Paramete Atmospheric / Observing Para Zenith Angle 0	covers Covers meters 50 0.123	axis) Is) H age	0.53 0.000 0.80 0.23 2.00 2.44	mas mas mas mas mas mas mas	111 100 0 144 445 444 194 Aperture 0 0 0% Parameters LGS Asterian LGS Power	nm nm nm nm nm nm	20 0 3.2 mas/n 29 Ti To F meter (i Squir Seeing-I	x reduc x reduc x reduc x reduc m conj Allocat Hz inpu Allocat Hz inpu Allocat Hz inpu Allocat Hz inpu Allocat Hz inpu Allocat inp/T ilt www.mas) ion of sk ion of sk 0.17 50	tition tition height ion height ion wit disturtion to the tition on the	%) 35 0.39 0.00	0.00 7.1 50 0.52 0.01 ed to the	0.00 9.1 70 0.59 0.02 Total Ef	0.02 11.8 90 0.60 0.03	0.07 14.3 120 0.61 0.05	0.15 16.8 240 0.66 0.18	0.25 19.6 400 0.73 0.42	0.39 23.7 800 0.84	30.9	0.7 41 44 0.5
Residual Almospheric Dispersion and Common Park III Park	ion on one of the control of the con	axis) If H age deg m arcsec	0.53 0.000 0.80 0.23 2.00 2.44	mas mas mas mas mas mas mas	111 100 0 144 444 145 44 194 Aperture 0 0% Parameters LGS Asterian LGS Power	nm nm nm nm nm nm	20 3.2 mas/s 29 Ti To F Seeing-1	x reduc x red	tition tition height ion height ion wit disturtion to the tition on the	%) 35 0.39 0.00	0.00 7.1 50 0.52 0.01 ed to the	0.00 9.1 70 0.59 0.02 Total Eff Magnitu 111.2	0.02 11.8 90 0.60 0.03	0.07 14.3 120 0.61 0.05	0.15 16.8 240 0.66 0.18	0.25 19.6 400 0.73 0.42	0.39 23.7 800 0.84 0.88	30.9	0.7 41 44 0.5
Residual Almospheric Dispersion Induced Plate Scie Deformation Monce Common Path Tip-Till Err Residual Telescope Pointing Ji TT Error Margin Total Tip/Tilt Error (ci stal Effective Wavefror Industrial Effective Wavefror Corresponding Sky Sumptions / Paramete Atmospheric / Observing Paramete Atmospheric / Observing Paramete Wind Speed Wind Speed Wind Speed Outer Scale	covers Covers meters 50 0.123 1.331 1.478 50	H H age deg m arcsec m/s m	0.53 0.000 0.808 0.23 2.000 2.4 Spa	mas mas mas mas mas mas mas	111 100 0 144 4 145 145 44 194 Aperture 0 0% 0% Parameters LGS Asterian LGS Power BTO Transmith HO WFS Tyel HO WFS Tyel	nm	20 3.2 mas/s 29 Ti To F Seeing-1	x reduc x red	rehl (mas 15 0.11 0.00 arcmin W	%) 35 0.39 0.00	0.00 7.1 50 0.52 0.01 LO WFS 111.2 Derived	0.00 9.1 70 0.59 0.02 Total Et	0.02 11.8 90 0.60 0.03	0.07 14.3 120 0.61 0.05	0.15 16.8 240 0.66 0.18	0.25 19.6 400 0.73 0.42	0.39 23.7 800 0.84 0.88	30.9	0.7 41 44 0.5
Residual Almospheric Dispersi Induced Plate Scale Deformation Non-Common-Path Tip-Title Err Residual Telescope Pointing Ji TT Enror Margin Total Tip/Title Error (c Stall Effective Wavefror Stall Effective Wavefror Corresponding Sky Sumptions / Paramete Atmospheric / Observing Para Zenith Angle O thead _ etc.	covers Covers meters 50 0.123 1.331 1.478 50	H Age deg m arcsec m/s	0.53 0.000 0.808 0.23 2.000 2.4 Spa	mas mas mas mas mas mas mas	111 100 0 144 4 145 44 145 44 194 Aperture 0 0% Parameters LGS Asterian LGS Power BTO Transmit HO WFS Trigh HO WFS Trigh HO WFS Typh HO WFS Typh	nm n	20 3.2 mas/s 3.2 mas/s 29 Ti To F meter (t) Seeing-1	x reduce x red	rehl (mass 15 0.11 0.00 arcmin W	35 0.39 0.00	0.00 7.1 50 0.52 0.01 LO WFS 111.2 Derived	0.00 9.1 70 0.59 0.02 Total Et	0.02 11.8 90 0.60 0.03	0.07 14.3 120 0.61 0.05	0.15 16.8 240 0.66 0.18	0.25 19.6 400 0.73 0.42	0.39 23.7 800 0.84 0.88	30.9	0.7 41 44 0.5
Residual Almospheric Dispersi Induced Plate Scale Deformation Non-Common-Path Tip-Title Err Residual Telescope Pointing Ji TT Enror Margin Total Tip/Title Error (c Stall Effective Wavefror Stall Effective Wavefror Corresponding Sky Sumptions / Paramete Atmospheric / Observing Para Zenith Angle Outer Scale Outer Scale Godun Audiance AO Modes of Operation	Covers Covers 1.331 14.78 3 3	H H age deg m arcsec m/s m	0.53 0.000 0.808 0.23 2.000 2.4 Spa	mas mas mas mas mas mas mas	111 100 0 144 4 145 44 1194 1994 1994 1996 1996 1996 1996 1	nm n	20 as/s as/s 29 Ti	x reduce x red	rehl (mass to 0.11 0.00 y can b arcmin W using e-rms	35 0.39 0.00	0.00 7.1 50 0.52 0.01 LO WFS 111.2	0.00 9.1 70 0.59 0.02 Total Est HO WF3 Detecte	0.02 11.8 90 0.60 0.03 des 111.2 11.2 8 Rate d PDE/s	0.07 14.3 120 0.61 0.05	0.15 16.8 240 0.66 0.18 111.2 1023 48	0.25 19.6 400 0.73 0.42	0.39 23.7 800 0.84 0.88	30.9	0.7 41 44 0.5
Residual Atmospheric Dispersion Induced Plate Scole Deformation Induced Plate Scole Pedematic Induced Plate Scole Pedematic Induced Plate Scole Pedematic Interest In Part In Part Interest In Part Interest Inter	one-axi meters 50 0.123 1.331 14.78 50 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.0000 0.00	H age deg m m x 109 cm-	0.53 0.000 0.808 0.23 2.000 2.4 Spa	mas mas mas mas mas mas mas	111 100 0 144 4 145 445 4	nm n	20 as/s as/s 29 Ti	x reduce x red	tition tition height to he	35 0.39 0.00	0.00 7.1 50 0.52 0.01 LO WFS 111.2	0.00 9.1 70 0.59 0.02 Total Est HO WF3 Detecte	0.02 11.8 90 0.60 0.03 des 111.2 11.2 8 Rate d PDE/s	0.07 14.3 120 0.61 0.05	0.15 16.8 240 0.66 0.18 111.2 1023 48	0.25 19.6 400 0.73 0.42	0.39 23.7 800 0.84 0.88	30.9	0.7 41. 44 0.5
Residual Almospheric Dispersion Induced Plate Scie Deformation In Tener Margin Total Tip/Tilt Error (c Total Tip/Tilt Error (c Induced Plate Induced Pla	COVERS COVERS MOAD MOAD MOAD MOAD MOAD MOAD MOAD	H age deg m m x 109 cm-	0.53 0.000 0.808 0.23 2.000 2.4 Spa	mas mas mas mas mas mas mas	111 100 0 114 4 145 445 145 445 145 1	nm n	200 3.2 mas/s 29 Ti To F Seeing-1 This fract	x reduce x x x x x x x x x x x x x x x x x x x	rehl (massing e-rms using e-rms	35 0.39 0.00	0.00 7.1 50 0.52 0.01 LO WFS 111.2	0.00 9.1 70 0.59 0.02 Total Et	0.02 11.8 90 0.60 0.03 des 111.2 11.2 8 Rate d PDE/s	0.07 14.3 120 0.61 0.05	0.15 16.8 240 0.66 0.18 111.2 1023 48	0.25 19.6 400 0.73 0.42	0.39 23.7 800 0.84 0.88	30.9	0.7 41.
Residual Almospheric Dispersion Induced Plate Scale Deformation Monce Grant Plate Plate In Piliter Residual Teles Except Pointing Ji TT Error Margin Total Tip/Tilt Error (ci Interest Plate In Piliter Interest Plate In Piliter Interest Plate Inte	COVERS COVERS MOAD MOAD MOAD MOAD MOAD MOAD MOAD MOAD MOAD	H H age deg m mssec m/s m/s x 109 cm-s	0.53 0.000 0.808 0.23 2.000 2.4 Spa	mas mas mas mas mas mas mas	111 100 0 144 4 145 44 1145 44 194 194 196 197 197 197 197 197 197 197 197 197 197	nm n	200 3.2 mas/s 29 Ti To F Seeing-1 This fract	x reduc x red	rehl (massing e-rms using e-rms	35 0.39 0.00	0.00 7.1 50 0.52 0.01 LO WFS 111.2	0.00 9.1 70 0.59 0.02 Total Et	0.02 11.8 90 0.60 0.03 des 111.2 11.2 8 Rate d PDE/s	0.07 14.3 120 0.61 0.05	0.15 16.8 240 0.66 0.18 111.2 1023 48	0.25 19.6 400 0.73 0.42	0.39 23.7 800 0.84 0.88	30.9	0.7 41. 44 0.5
Residual Almospheric Dispersion Induced Plate Scale Deformation Mon-Common-Path Tip-Title Err Residual Telescope Pointing Jil TT Enror Margin Total Tip/Title Error (c) Total Tip/Title Error (c) Total Tip/Title Error (c) Total Effective Wavefror Stale Effective Wavefror (c) Tip/Title Error (c) Total Tip/Title Error (c) Ti	ion	H age deg marssec my/s my x 109 cm-	0.53 0.000 0.808 0.23 2.000 2.4 Spa	mas mas mas mas mas saxel /	111 100 0 114 4 145 445 145 445 145 1	nm n	200 3.2 mas/s 29 Ti To F Seeing-1 This fract	x reduce x x x x x x x x x x x x x x x x x x x	tition height ion height ion with disturbing the disturbing height ion street (mass). The street is street in the street is street in the stre	35 0.39 0.00	0.00 7.1 50 0.52 0.01 LO WFS 111.2	0.00 9.1 70 0.59 0.02 Total Et	0.02 11.8 90 0.60 0.03 des 111.2 11.2 8 Rate d PDE/s	0.07 14.3 120 0.61 0.05	0.15 16.8 240 0.66 0.18 111.2 1023 48	0.25 19.6 400 0.73 0.42	0.39 23.7 800 0.84 0.88	30.9	0.7 41. 44 0.5

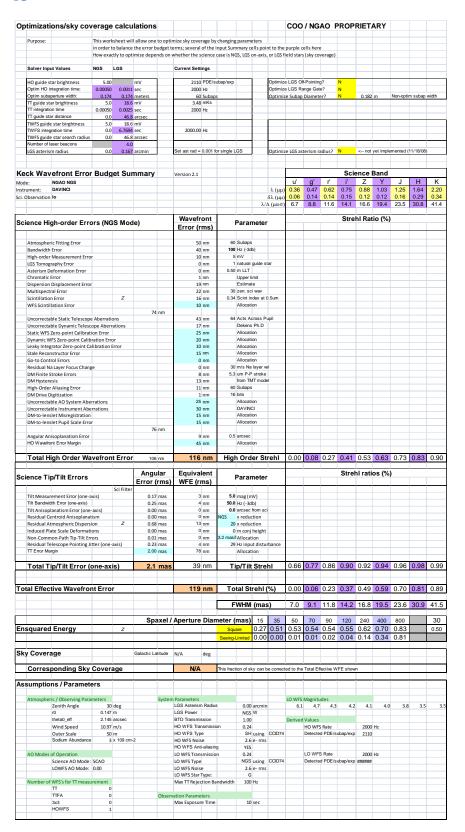
Exo-planets

This works	sheet wil	l allow one	to optir	nize sky cove	rage by	changing	parame	eters										
		illize depe	ius oii v			case is ive	33, 103 (JII-dais,	01 203 11	ieiu stais	(SKY CO	verage)						
NGS I	LGS			Current Sett	ings													
LGS		mV				ubap/exp							N					
														0 182	m	Non-ontin	m suhan	width
LGS	16.0	mV		13.40	mKs				Орини	С Эшопр	Diame to			0.101				
				2000	Hz													
LGS	16.0	mV																
				0.50	Hz													
0.0	4.0	arcsec								_								
0.0	0.167	arcmin		Set ast rad =	0.001 f	or single L	.GS		Optimiz	e LGS ast	erism ra	idius?	N	< not	yet imple	mented (11/18/08)	
Budge	et Sur	nmary		Version 2.1									Scie	ence	Band			
										u'	g'	ď	i'	Z	Υ	J	Н	K
																		0.3
																		41.
									(даст)	-								
rs (LG	S Mod	le)					Paran	neter					Stre	hl Rat	io (%)			
		_		Error (r	ms)													
								b)										
								con(s)										
				16	nm	0.50	m LLT											
\vdash																		
							zen; sc	wav										
	Н			12	nm	0.34).5um									
		116	nm	10	nm		Allocati	on										
		110							ıpil									
	itions																	
	r																	
				10	nm													
e						30			ı									
									1									
				1	nm	16												
r				15	nm		Allocati	on										
		97	nm	16	nm	10	arcsec											
								on										
	F			450		110-1	. 0-4	C4		0.00	0.04	0.00	0.40	0.00	0.40	0.54	0.70	0.0
verront	Error	151	nm	158	nm	nıgı	Ora	er Sti	reni	0.00	0.01	0.08	0.18	0.29	0.40	0.54	0.70	0.8
		Angu	lar	Equiva	lent		Doror						Strel	hl rati	os (%))		
		Error (rms)	WFE (r	ms)	'	raiai	neter										
	Sci Filter	7.50	mar	121	nm	18 3	mag/m	M)										
(is)						50.0	Hz (-3d	b)										
axis)						0.0	arcsec	from sci										
	Н																	
ons		0.00	mas	C	nm	0	m conj	height										
			mas		nm	3.2 mas/	Allocat	ion										
ors	vic)																	
ors tter (one-a	xis)	0.23	mas		nm	29	Hz inpu	t distur	bance									
tter (one-a		0.23 2.00	mas	145	nm		Hz inpu Allocat	t distur										
ors tter (one-a		0.23 2.00			nm		Hz inpu	t distur		0.13	0.20	0.31	0.40	0.48	0.56	0.65	0.76	3.0
tter (one-a		0.23 2.00	mas	145	nm		Hz inpu Allocat	t distur		0.13	0.20	0.31	0.40	0.48	0.56	0.65	0.76	8.0
tter (one-a	s)	0.23 2.00	mas	136	nm	Ti	Hz inpu Allocat	t distur ion Strel	hl				0.40				0.76	
one-axis	s)	0.23 2.00	mas	136	nm	Ti	Allocat p/Tilt tal St	Strel	hl %)	0.00	0.00	0.02	0.07	0.14	0.22	0.35	0.53	0.7
one-axis	s)	0.23 2.00	mas	136	nm	Ti	Hz inpu Allocat p/Tilt	Strel	hl %)	0.00	0.00	0.02		0.14	0.22	0.35	0.53	0.7
one-axis	s)	0.23 2.00 7.8	mas	136	nm nm	Ti To	Hz Inpu Allocat p/T ilt tal St	Strel	hl %)	0.00	0.00	0.02	0.07	0.14	0.22	0.35	0.53	0.7
one-axis	s)	0.23 2.00 7.8	mas	136	nm nm	Ti To	Hz inpu Allocat p/T ilt tal St WHM mas)	Strel	hl %)	0.00	0.00	0.02	0.07	0.14	0.22	0.35	0.53	0.7
one-axis	s)	0.23 2.00 7.8	mas	136	nm nm	To F	Hz inpu Allocat p/Tilt tal St WHM mas)	Strel rehl (mas 15 0.13	%) 35	0.00 10.3 50 0.61	0.00 11.8 70 0.69	0.02 14.0 90 0.71	16.1	0.14 18.4 240 0.75	0.22 20.9 400 0.80	0.35 24.8 800 0.86	0.53	0.7
one-axis	s)	0.23 2.00 7.8	mas mas	145 136 207 Aperture	nm nm Dian	To Feneter (Hz inpu Allocat p/Tilt tal St WHM mas)	Strel rehl (mas 15 0.13	hl %) 35 0.45	0.00 10.3 50 0.61	0.00 11.8 70 0.69	0.02 14.0 90 0.71	0.07 16.1 120 0.72	0.14 18.4 240 0.75	0.22 20.9 400 0.80	0.35 24.8 800 0.86	0.53	0.7
one-axis	s)	0.23 2.00 7.8	mas mas	145 136 207 Aperture	nm nm	To Feneter (Hz inpu Allocat p/Tilt tal St WHM mas)	Strel rehl (mas 15 0.13	hl %) 35 0.45	0.00 10.3 50 0.61	0.00 11.8 70 0.69	0.02 14.0 90 0.71	0.07 16.1 120 0.72	0.14 18.4 240 0.75	0.22 20.9 400 0.80	0.35 24.8 800 0.86	0.53	0.7
one-axis	н	0.23 2.00 7.8	mas mas	145 136 207 Aperture	nm nm Dian	To Foundation of the second o	Hz inpu Allocat p/T ilt tal St WHM mas) are	rehl (mas 15 0.13 0.00	%) 35 0.45 0.00	0.00 10.3 50 0.61	0.00 11.8 70 0.69 0.02	0.02 14.0 90 0.71 0.03	0.07 16.1 120 0.72 0.05	0.14 18.4 240 0.75 0.18	0.22 20.9 400 0.80	0.35 24.8 800 0.86	0.53	0.7
one-axis	н	0.23 2.00 7.8	mas mas	145 136 207 Aperture	nm nm Dian	To Foundation of the second o	Hz inpu Allocat p/T ilt tal St WHM mas) are	rehl (mas 15 0.13 0.00	%) 35 0.45 0.00	0.00 10.3 50 0.61 0.01	0.00 11.8 70 0.69 0.02	0.02 14.0 90 0.71 0.03	0.07 16.1 120 0.72 0.05	0.14 18.4 240 0.75 0.18	0.22 20.9 400 0.80	0.35 24.8 800 0.86	0.53	0.7
one-axis	н	0.23 2.00 7.8	mas mas	145 136 207 Aperture	nm nm Dian	To Foundation of the second o	Hz inpu Allocat p/T ilt tal St WHM mas) are	rehl (mas 15 0.13 0.00	%) 35 0.45 0.00	0.00 10.3 50 0.61 0.01	0.00 11.8 70 0.69 0.02	0.02 14.0 90 0.71 0.03	0.07 16.1 120 0.72 0.05	0.14 18.4 240 0.75 0.18	0.22 20.9 400 0.80	0.35 24.8 800 0.86	0.53	0.7
one-axis	н	0.23 2.00 7.8	mas mas mas titude	145 136 207 Aperture	nm nm Dian	To Foundation of the second o	Hz inpu Allocat p/T ilt tal St WHM mas) are	rehl (mas 15 0.13 0.00	%) 35 0.45 0.00	0.00 10.3 50 0.61 0.01	0.00 11.8 70 0.69 0.02	0.02 14.0 90 0.71 0.03	0.07 16.1 120 0.72 0.05	0.14 18.4 240 0.75 0.18	0.22 20.9 400 0.80	0.35 24.8 800 0.86	0.53	0.7
covera	H deg	0.23 2.00 7.8	mas mas mas saxel /	145 136 207 Aperture 30 0%	nm nm Dian	To Feeter (Squ Seeing-	Hz inpu Allocat p/Tilt whm mas) are Limited 0.17	Strel Strel (mas 15 0.13 0.00	%) 35 0.45 0.00	0.00 10.3 50 0.61 0.01	0.00 11.8 70 0.69 0.02	0.02 14.0 90 0.71 0.03	0.07 16.1 120 0.72 0.05	0.14 18.4 240 0.75 0.18	0.22 20.9 400 0.80	0.35 24.8 800 0.86 0.88	0.53	0.7
Covera Covera One-axis	н nge	0.23 2.00 7.8	mas mas masel /	145 136 207 Aperture 30 0% Parameters LGS Asterisr LGS Asterisr	nm nm Dian deg	To Feeter (Squ Seeing-	Hz inpu Allocat p/T ilt tal St WHM mas) are Limited 0.17 50	Strel Strel (mass 15 0.13 0.00 arcmin W	%) 35 0.45 0.00	0.00 10.3 50 0.61 0.01 ed to the	0.00 11.8 70 0.69 0.02 Total Eff	0.02 14.0 90 0.71 0.03	0.07 16.1 120 0.72 0.05	0.14 18.4 240 0.75 0.18	0.22 20.9 400 0.80 0.42	0.35 24.8 800 0.86 0.88	0.53	0.7 42 30 0.5
covera	H H age	0.23 2.00 7.8	mas mas mas system	145 136 207 Aperture 30 0%	nm nm Dian deg	Tioneter (Squ Seeing-	Hz inpu Allocat p/Tilt whm mas) are Limited 0.17	Strel Strel (mass 15 0.13 0.00 arcmin W	%) 35 0.45 0.00	0.00 10.3 50 0.61 0.01 ed to the	0.00 11.8 70 0.69 0.02 Total Eff	90 0.71 0.03	0.07 16.1 120 0.72 0.05	0.14 18.4 240 0.75 0.18	0.22 20.9 400 0.80 0.42	0.35 24.8 800 0.86 0.88	0.53	0.7 42 30 0.5
Covera Covera 10.145 a 10.97 c 10.55	H H dege deg mm/s mm/s	0.23 2.00 7.8 Spa	mas mas axel /	145 207 207 Aperture 30 0% Parameters LGS Asterior BTO Transmit HO WFS Tra	nm nm Dian Dian Radiur	Tioneter (Squ Seeing-	Hz Inpu Allocat Alloca	strel (mass 15 0.13 0.00 ry can b arcmin W	%) 35 0.45 0.00	0.00 10.3 50 0.61 0.01 ed to the	0.00 11.8 70 0.69 0.02 Total Eff 18.6 Values	0.02 14.0 90 0.71 0.03	0.07 16.1 120 0.72 0.05	0.14 18.4 240 0.75 0.18	0.22 20.9 400 0.80 0.42	0.35 24.8 800 0.86 0.88	0.53	0.7 42 30 0.5
Covera Covera 10.145 a 10.97 c 10.55	H H age	0.23 2.00 7.8 Spa	mas	Aperture 207 Aperture 30 0% Parameters LGS Asterisr LGS Power BTO Transmith HO WFS Note HO WFS Typ HO WFS Typ	nm nm nm deg deg	To F Feneter (Squ Seeing- This fract	Hz Inpu Allocat Alloca	strel (mass 15 0.13 0.00 arcmin W	%) 35 0.45 0.00	0.00 10.3 50 0.61 0.01 ed to the	0.00 11.8 70 0.69 0.02 Total Eff 18.6 Values	0.02 14.0 90 0.71 0.03	0.07 16.1 120 0.72 0.05	0.14 18.4 240 0.75 0.18	0.22 20.9 400 0.80 0.42	0.35 24.8 800 0.86 0.88	0.53	0.5 42 3 0.5
Covera Covera 10.145 a 10.97 c 10.55	H H dege deg mm/s mm	0.23 2.00 7.8 Spa	mas mas mas system	145 207 207 Aperture 30 0% Parameters LGS Asterior BTO Transmit HO WFS Tra	nm nm nm Dian deg ssion nsmission eesee i-aliasin	To Formater (Squ Seeing- This fract	Hz Inpu Allocat Alloca	rehl (mass 15 0.13 0.00 arcmin W using e-ms	%) 35 0.45 0.00	0.00 10.3 50 0.61 0.01 LOWFS: 19.3 Derived	0.00 11.8 70 0.69 0.02 Total Eff	0.02 14.0 90 0.71 0.03 ective W.	0.07 16.1 120 0.72 0.05	0.14 18.4 240 0.75 0.18	0.22 20.9 400 0.80 0.42	0.35 24.8 800 0.86 0.88	0.53	0.7 42 30 0.5
one-axister (one-a-axister (one-a-axister one-axister	H H deg mm marcsec mm/s mm x 109 cm-	0.23 2.00 7.8 Spa	mas mas axel /	Aperture 30 Aperture 30 0% Parameters LGS Asterian LGS Power B10 Transmit H0 WFS Try H0 WFS Try H0 WFS Noi: H0 WFS Noi: U0 WFS Try U0 WFS	nm nm Dian deg deg	To Formater (Squ Seeing- This fract	Hz input Allocat Allocat St Tall St Ta	strel (mas 15 0.13 0.00 y can b arcmin W	hl 35 0.45 0.00 ccib74	0.00 10.3 50 0.61 0.01 LOWFS: 19.3 Derived	0.00 11.8 70 0.69 0.02 Total Eff	0.02 14.0 90 0.71 0.03 ective W.	0.07 16.1 120 0.72 0.05	0.14 18.4 240 0.75 0.18	0.22 20.9 400 0.80 0.42	0.35 24.8 800 0.86 0.88	0.53	0.7 42 36 0.5
Coverameters 30 0.147 rg 1.149 rg 90 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3	H H deg mm marcsec mm/s mm x 109 cm-	0.23 2.00 7.8 Spa	mas mas mas saxel /	Aperture 207 Aperture 30 0% Parameters LGS Asteriar LGS Power BTO Transm HO WFS Typ HO WFS Not HO WFS Not HO WFS Typ LO WFS Note LO WFS Typ LO WFS TY	nm nm Dian Dian deg deg in Radius	To Formater (Squ Seeing- This fract	Hz input Allocat Allocat St Tall St Ta	strel Strel (mas 15 0.13 0.00 arcmin w using e- ms using e- ms	hl 35 0.45 0.00 ccib74	0.00 10.3 50 0.61 0.01 LOWFS: 19.3 Derived	0.00 11.8 70 0.69 0.02 Total Eff	0.02 14.0 90 0.71 0.03 ective W.	0.07 16.1 120 0.72 0.05	0.14 18.4 240 0.75 0.18	0.22 20.9 400 0.80 0.42	0.35 24.8 800 0.86 0.88	0.53	0.7 42 36 0.5
Covera Covera	H H deg mm marcsec mm/s mm x 109 cm-	0.23 2.00 7.8 Spa	mas mas mas saxel /	Aperture 30 Aperture 30 0% Parameters LGS Asterian LGS Power B10 Transmit H0 WFS Try H0 WFS Try H0 WFS Noi: H0 WFS Noi: U0 WFS Try U0 WFS	nm nm Dian deg deg i-aliasinssmissio e Type:	To To F F Squ Seeing- This fract	Hz inpu. Allocat Alloc	strein st	hl 35 0.45 0.00 ccid74	0.00 10.3 50 0.61 0.01 LOWFS: 19.3 Derived	0.00 11.8 70 0.69 0.02 Total Eff	0.02 14.0 90 0.71 0.03 ective W.	0.07 16.1 120 0.72 0.05	0.14 18.4 240 0.75 0.18	0.22 20.9 400 0.80 0.42	0.35 24.8 800 0.86 0.88	0.53	0.7 42 36 0.5
Covera Covera 11 Error Covera 12 15 16 17 17 17 17 17 17 17 17 17 17 17 17 17	H H deg mm marcsec mm/s mm x 109 cm-	0.23 2.00 7.8 Spa	mas mas mas system	Aperture 30 0% Parameters LGS Asterisr LGS Asterisr HO WFS Tyr HO WFS Tyr HO WFS Tyr HO WFS Tyr U O WFS Tyr LO WFS No:	nm nm nm Dian deg deg deg deg tripe:	To To F F Squ Seeing- This fract	Hz inpu Allocat p/Tilt tal St WHM mas) one of sie 0.17 50 0.60 0.38 NO 0.29 SH 3.2 M	strein st	hl 35 0.45 0.00 ccid74	0.00 10.3 50 0.61 0.01 LOWFS: 19.3 Derived	0.00 11.8 70 0.69 0.02 Total Eff	0.02 14.0 90 0.71 0.03 ective W.	0.07 16.1 120 0.72 0.05	0.14 18.4 240 0.75 0.18	0.22 20.9 400 0.80 0.42	0.35 24.8 800 0.86 0.88	0.53	0.7 42 30 0.5
	How exact LOS 0.0050 0.0050 0.105 0.00 0.00 0.00 0.	How exactly to opt	Nos Los mV	Nos LoS	Nos LoS	Now Note N	How exactly to optimize depends on whether the science case is Not	Nos Los Current Settings	Nos LoS	Nos	How exactly to optimize depends on whether the science case is NGS, LGS on-axis, or LGS field stars. NGS	How exactly to optimize depends on whether the science case is NGS, LGS on-axis, or LGS field stars (sky cor NGS	1.05	Nos LGS	Nos Los Current Settings Current Settings	Nos Los Current Settings Current Settings	Nos Los Current Settings Signature depends on whether the science case is NGS, LGS on-axis, or LGS field stars (sky coverage) Signature continues of the stars (sky coverage) Signature	Nos LoS

Minor Planets

Purpose:	ons/sky cov					nize sky cove	rage by	changing	naram	iters					PROP					
rurpose:		in order t	o balance	the error b	udget t	erms; several	of the	nput Sun	nmary ce	lls poir										
		How exac	tly to opt	imize depe	nds on v	whether the s	cience	case is No	GS, LGS o	n-axis,	or LGS f	ield stars	(sky co	verage)						
Solver Inpu	ıt Values	NGS	LGS			Current Sett	ings													
HO guide st	ar brightness	LGS		mV		57	PDE/s	ubap/exp			Optimize	LGS Of	-Pointing	9?	N					
Optim HO in	ntegration time:	0.00050	0.0011	sec		951	Hz					e LGS Ra			N					1.64
	perture width: ar brightness	0.174 LGS		meters mV			Subap mKs	S			Optimiz	e Subap	Diamete	er?	N	0.182	m	Non-opti	n subap	width
TT integratio	n time	0.00050	0.0025			400	Hz													
TT guide sta TWFS guide		LGS		arcsec mV																
TWFS integr	ration time	0.0	6.7694	sec		0.15	Hz													
Number of Is	star search radius aser beacons	0.0	46.8	arcsec																_
LGS asterisr	m radius	0.0	0.167	arcmin		Set ast rad =	0.001 f	or single L	.GS		Optimiz	e LGS as	erism ra	adius?	N	< not	yet imple	mented (11/18/08)	1
eck Wav	efront Error	Budg	et Su	mmary		Version 2.1									Scie	ence l	Band			
iouc.	NGAO LGS											u'	g'	ď	i'	Z		J	Τ	K
	DAVINCI Minor Planets										λ (μμ) δλ (μμ)	0.36	0.47 0.14	0.62	0.75 0.15	0.88	1.03 0.12	1.25 0.16	1.64 0.29	0.3
i. Observation	minor i rancis										ι (μασ)	6.7	8.8	11.6	14.1	16.6	19.4	23.5	30.8	
						18/									C4==	LI D-4	:- (0/)			
cience Hig	gh-order Erro	ors (LG	S Mod	le)		Wavefr Error (r			Paran	neter					Stre	hl Rat	10 (%)			
Atmorphori	ic Fitting Error						nm	60	Subaps											
Bandwidth	Error						nm	48	Hz (-3di											
High-order	Measurement Erro	-				66	nm	50	W											
LGS Tomogr Asterism De	raphy Error eformation Error						nm		sci bead m LLT											
Chromatic E							nm		Upper li	mit										
Dispersion I Multispectr	Displacement Error ral Error						nm nm	30	Estimat zen; sci											
Scintillation	n Error		Z			16	nm		Scint in	dex at 0	.5um									
WFS Scintill	lation Error			115	nm	10	nm		Allocati	on										
	ble Static Telescope				Ü		nm		Acts Ac		pil									
	ble Dynamic Telesc Zero-point Calibrati		ations				nm		Dekens											
Dynamic WI	FS Zero-point Calib	ration Erro				25	nm		Allocati	on										
	rator Zero-point Ca structor Error	libration E	rror				nm	-	Allocati											
Go-to Contr							nm		Allocati											
	Layer Focus Chang	e					nm		m/s Na um P-P		I									
DM Finite S DM Hystere	troke Errors esis					13	nm nm		from TM	IT mode	ı									
	Aliasing Error						nm		Subaps bits											
DM Drive Di Uncorrectat	igitization ble AO System Abe	rrations					nm	10	Allocati	on										
Uncorrectab	ble Instrument Abe	rrations				30	nm		DAVING											
	let Misregistration let Pupil Scale Erro						nm		Allocati											
				100	nm															
	isoplanatism Error nt Error Margin						nm	0.0	arcsec Allocati	on										
Total Hi	igh Order Wa	vefron	t Error	152	nm	159	nm	Higl	n Ord	er Stı	rehl	0.00	0.01	80.0	0.17	0.29	0.40	0.54	0.69	0.8
				Angu		Equiva	lent								Strel	hl rati	os (%)		
cience Tip	o/Tilt Errors					1A/FF (Paran	neter										
cience Tip	p/Tilt Errors		Sci Filter	Littory	rms)	WFE (r	ms)		Paran	neter										
	ement Error (one-a		Sci Filter	2.42	mas	40	nm	18.6	mag (m	V)										
Tilt Measure Tilt Bandwid	ement Error (one-a lth Error (one-axis)	xis)	Sci Filter	2.42	mas mas	40	nm	18.6 16.7		V) b)										
Tilt Measure Tilt Bandwid Tilt Anisopl Residual Ce	ement Error (one-a lth Error (one-axis) anatism Error (one- entroid Anisoplanat	xis) -axis) ism		2.42 0.74 3.60 0.55	mas mas mas mas	40 13 59	nm nm nm	18.6 16.7 46.8 20	mag (m Hz (-3d) arcsec i x reduc	V) b) from sci										
Tilt Measuri Tilt Bandwid Tilt Anisopla Residual Ce Residual At	ement Error (one-a th Error (one-axis) anatism Error (one-	axis) axis) ism	Sci Filter	2.42 0.74 3.60 0.55 0.68	mas mas mas	40 13 59 9	nm nm	18.6 16.7 46.8 20 20	mag (m Hz (-3d arcsec	V) b) from sci tion tion										
Tilt Measure Tilt Bandwid Tilt Anisopli Residual Ce Residual At Induced Pla Non-Comm	ement Error (one-a th Error (one-axis) anatism Error (one- entroid Anisoplanat mospheric Dispersi ste Scale Deformati ion-Path Tip-Tilt Err	axis) -axis) ism on ons	Z	2.42 0.74 3.60 0.55 0.68 0.00	mas mas mas mas mas mas	40 13 59 9 13 0	nm nm nm nm nm	18.6 16.7 46.8 20 20 0 3.2 mas/	mag (m Hz (-3d arcsec x reduc x reduc m conj	V) b) from sci tion tion height ion										
Tilt Measure Tilt Bandwid Tilt Anisopl: Residual Ce Residual At Induced Pla Non-Comm	ement Error (one-a th Error (one-axis) anatism Error (one- entroid Anisoplanat mospheric Dispersi ste Scale Deformati ion-Path Tip-Tilt Err descope Pointing Ji	axis) -axis) ism on ons	Z	2.42 0.74 3.60 0.55 0.68 0.00 0.11	mas mas mas mas mas	40 13 59 9 13 0 2	nm nm nm nm nm	18.6 16.7 46.8 20 20 0 3.2 mas/	mag (m Hz (-3d) arcsec x reduc x reduc m conj	V) from sci tion tion height ion t distur	bance									
Tilt Measurd Tilt Bandwid Tilt Anisopl Residual Ce Residual At Induced Pla Non-Comm Residual Te TT Error Mar	ement Error (one-a th Error (one-axis) anatism Error (one- introid Anisoplanat mospheric Dispersi ate Scale Deformati ion-Path Tip-Tilt Err elescope Pointing Ji rgin	xis) -axis) ism on ons ors tter (one-	Z axis)	2.42 0.74 3.60 0.55 0.68 0.00 0.11 0.70 2.00	mas mas mas mas mas mas mas mas	40 13 59 9 13 0 2	nm nm nm nm nm nm nm	18.6 16.7 46.8 20 20 0 3.2 mas/ 29	mag (m Hz (-3d) arcsec l x reduc x reduc m conj Allocati Hz inpu Allocati	V) b) from sci tion tion height ion t distur										
Tilt Measurd Tilt Bandwid Tilt Anisopl Residual Ce Residual At Induced Pla Non-Comm Residual Te TT Error Mar	ement Error (one-a th Error (one-axis) anatism Error (one- entroid Anisoplanat mospheric Dispersi ste Scale Deformati ion-Path Tip-Tilt Err descope Pointing Ji	xis) -axis) ism on ons ors tter (one-	Z axis)	2.42 0.74 3.60 0.55 0.68 0.00 0.11 0.70 2.00	mas mas mas mas mas mas mas	40 13 59 9 13 0 2	nm nm nm nm nm nm	18.6 16.7 46.8 20 20 0 3.2 mas/ 29	mag (m Hz (-3di arcsec i x reduc x reduc m conj Allocati Hz inpu	V) b) from sci tion tion height ion t distur		0.27	0.39	0.53	0.62	0.69	0.76		0.89	0.9
Tilt Measur Tilt Bandwid Tilt Anisopl. Residual Ce Residual At Induced Pla Non-Comm Residual Te TT Error Mar	ement Error (one-asi) th Error (one-asis) anatism Error (one-asis) anatism Error (anisoplanat mospheric Dispersi the Scale Defores ton-Path Tip-Tilt Err lescope Pointing Ji gin p/Tilt Error (d	xis) -axis) ism ion ons ors tter (one-a	z axis)	2.42 0.74 3.60 0.55 0.68 0.00 0.11 0.70 2.00	mas mas mas mas mas mas mas mas	40 13 59 9 13 0 2 12 78	nm nm nm nm nm nm nm nm	18.6 16.7 46.8 20 0 3.2 mas/ 29	mag (m Hz (-3d) arcsec x reduc x reduc m conj Allocati Hz inpu Allocati	V) b) from sci tion tion height ion t distur ion	nl							0.82		
Tilt Measur Tilt Bandwid Tilt Anisopi. Residual Ce Residual At Induced Pla Non-Comm Residual Te TT Error Mar	ement Error (one-a th Error (one-axis) anatism Error (one- introid Anisoplanat mospheric Dispersi ate Scale Deformati ion-Path Tip-Tilt Err elescope Pointing Ji rgin	xis) -axis) ism ion ons ors tter (one-a	z axis)	2.42 0.74 3.60 0.55 0.68 0.00 0.11 0.70 2.00	mas mas mas mas mas mas mas mas	40 13 59 9 13 0 2 12 78	nm nm nm nm nm nm nm	18.6 16.7 46.8 20 20 0 3.2 mas/ 29	mag (m Hz (-3d) arcsec i x reduc x reduc m conj Allocati Hz inpu Allocati p/T ilt	V) b) from sci tion tion height ion t distur ion Strel	nl %)		0.00	0.04	0.11	0.20	0.30	0.82	0.62	0.7
Tilt Measur Tilt Bandwid Tilt Anisopi. Residual Ce Residual At Induced Pla Non-Comm Residual Te TT Error Mar	ement Error (one-asi) th Error (one-asis) anatism Error (one-asis) anatism Error (anisoplanat mospheric Dispersi the Scale Defores ton-Path Tip-Tilt Err lescope Pointing Ji gin p/Tilt Error (d	xis) -axis) ism ion ons ors tter (one-a	z axis)	2.42 0.74 3.60 0.55 0.68 0.00 0.11 0.70 2.00	mas mas mas mas mas mas mas mas	40 13 59 9 13 0 2 12 78	nm nm nm nm nm nm nm nm	18.6 16.7 46.8 20 20 0 3.2 mas/ 29	mag (m Hz (-3d) arcsec x reduc x reduc m conj Allocati Hz inpu Allocati	V) b) from sci tion tion height ion t distur ion Strel	nl %)		0.00	0.04		0.20	0.30	0.82	0.62	0.7
Tilt Measur Tilt Bandwid Tilt Anisopi. Residual Ce Residual At Induced Pla Non-Comm Residual Te TT Error Mar	ement Error (one-asi) th Error (one-asis) anatism Error (one-asis) anatism Error (anisoplanat mospheric Dispersi the Scale Defores ton-Path Tip-Tilt Err lescope Pointing Ji gin p/Tilt Error (d	xis) -axis) ism ion ons ors tter (one-a	z axis)	2.42 0.74 3.60 0.55 0.68 0.00 0.11 0.77 2.00	mas mas mas mas mas mas mas mas mas	40 13 59 9 13 0 2 12 78	nm nm nm nm nm nm nm nm nm	18.6 16.7 46.8 20 20 0 3.2 mas/ 29	mag (m Hz (-3d) arcsec (x reduc x reduc m conj Allocati Hz inpu Allocati p/T ilt	V) b) from sci tion tion height ion t distur ion Strel	%) 35	0.00	0.00	0.04	0.11	0.20	0.30	0.82	0.62	0.7
Tilt Measur Tilt Bandwid Tilt Anisopi. Residual Ce Residual At Induced Pla Non-Comm Residual Te TT Error Mar	ement Error (one-axis) anatism Error (one-axis) anatism Error (one- ntroid Anisoplanat mospheric Dispersi te Scale Deformati te Scale Deformati te Scale Deformati por-Path Tip-Tilt Err lescope Pointing Ji p/Tilt Error (d	xis) -axis) ism ion ons ors tter (one-a	z axis)	2.42 0.74 3.60 0.55 0.68 0.00 0.11 0.77 2.00	mas mas mas mas mas mas mas mas mas	400 133 555 55 55 55 55 55 55 55 55 55 55 55	nm nm nm nm nm nm nm nm nm	18.6 16.7 46.8 20 0 3.2 mas/ 29 Ti To F neter (Squ	mag (m Hz (-3d) arcsec to x reduce x reduce m conj Allocat Hz inpu Allocat tal Sti WHM	VV) bb) from sci tion tion height ion Strel (mas 15 0.15	%) 35 0.28	0.00 8.3 50 0.29	0.00 10.1 70 0.30	0.04 12.6 90 0.31	0.11 14.9 120 0.32	0.20 17.3 240 0.40	0.30 20.0 400 0.51	0.82 0.44 24.1 800 0.69	0.62	0.7
Tilt Measur Tilt Bandwid Tilt Anisopi. Residual Ce Residual At Induced Pla Non-Comm Residual Te TT Error Mar Total Ti	ement Error (one-axis) anatism Error (one-axis) anatism Error (one- ntroid Anisoplanat mospheric Dispersi te Scale Deformati te Scale Deformati te Scale Deformati por-Path Tip-Tilt Err lescope Pointing Ji p/Tilt Error (d	xis) -axis) ism ion ons ors tter (one-a	z axis) is)	2.42 0.74 3.60 0.55 0.68 0.00 0.11 0.77 2.00	mas mas mas mas mas mas mas mas mas	400 133 555 55 55 55 55 55 55 55 55 55 55 55	nm nm nm nm nm nm nm nm nm	18.6 16.7 46.8 20 20 0 3.2 mas/ 29 Ti	mag (m Hz (-3d) arcsec to x reduce x reduce m conj Allocat Hz inpu Allocat tal Sti WHM	VV) bb) from sci tion tition height ion Strei (mas	%) 35	0.00 8.3	0.00 10.1 70 0.30	0.04 12.6 90 0.31	0.11 14.9	0.20 17.3 240 0.40	0.30 20.0 400 0.51	0.82 0.44 24.1 800 0.69	0.62	0.7 41.
Tilt Measur Tilt Bandwid Tilt Anisopi. Residual Ce Residual At Induced Pla Non-Comm Residual Te TT Error Mar Total Ti	ement Error (one-assis) int Error (one-assis) anatism Error (one-intro) anatism Error (one troid Anisoplanic Objective to Sale Deformation Path Ip-Till Error (one till Escope Pointing Jil pp/Till Error (one till Escope Pointing Jil title Wavefror Energy	xis) -axis) ism ion ons ors tter (one-a	z axis) is)	2.42 0.74 3.60 0.55 0.68 0.00 0.11 0.77 2.00	mas	400 133 585 9 133 0 2 122 122 788 85	nm nm nm nm nm nm nm nm nm	18.6 16.7 46.8 20 0 3.2 mas/ 29 Ti To F neter (Squ	mag (m Hz (-3d) arcsec to x reduce x reduce m conj Allocat Hz inpu Allocat tal Sti WHM	VV) bb) from sci tion tion height ion Strel (mas 15 0.15	%) 35 0.28	0.00 8.3 50 0.29	0.00 10.1 70 0.30	0.04 12.6 90 0.31	0.11 14.9 120 0.32	0.20 17.3 240 0.40	0.30 20.0 400 0.51	0.82 0.44 24.1 800 0.69	0.62	0.7 41.
Tilt Measur. Till Bandwid Tilt Anisopl. Residual Ce Residual At Induced Pla Non-Comm Residual T TT Error Mar Total Ti Total Ti nsquared	ement Error (one-assis) anatism Error (one-assis) anatism Error (one- troid Ansioplant and mospheric Dispersit to Sale Deformation Path In-Pittle Err pfTitt Error (if the Wavefroi Energy Energy	xis) -axis) ism ion ons ors tter (one-axi	z axis) is) r	2.42 0.74 3.60 0.55 0.68 0.00 0.11 0.77 2.00	mas	400 133 555 555 555 555 555 555 555 555 555	nm nm nm nm nm nm nm nm	18.6 16.7.1 46.8 20 20 20 3.2 mas/s Ti	mag (m Hz (-3d) arcsec to x reduc x reduc x reduc x reduc to x reduc to x reduc to x reduc to x reduc to x reduc to x reduc to y red	V) bb) from sci tion height tion Strel (mas 15 0.00	%) 35 0.28 0.00	0.00 8.3 50 0.29 0.01	0.00 10.1 70 0.30 0.01	0.04 12.6 90 0.31 0.02	0.11 14.9 120 0.32 0.04	0.20 17.3 240 0.40 0.14	0.30 20.0 400 0.51	0.82 0.44 24.1 800 0.69	0.62	0.7 41.
Tilt Measur Till Bandwid Till Anisoph Residual Ce Residual At Induced Pla Non-Comm Residual Te TT Error Mar Total Ti	ement Error (one-assis) int Error (one-assis) anatism Error (one-intro) anatism Error (one troid Anisoplanic Objective to Sale Deformation Path Ip-Till Error (one till Escope Pointing Jil pp/Till Error (one till Escope Pointing Jil title Wavefror Energy	xis) -axis) ism ion ons ors tter (one-axi	z axis) is) r	2.42 0.74 3.60 0.55 0.68 0.00 0.11 0.77 2.00	mas	400 133 585 9 133 0 2 122 122 788 85	nm nm nm nm nm nm nm nm	18.6 16.7.1 46.8 20 20 20 3.2 mas/s Ti	mag (m Hz (-3d) arcsec to x reduc x reduc x reduc x reduc to x reduc to x reduc to x reduc to x reduc to x reduc to x reduc to y red	V) bb) from sci tion height tion Strel (mas 15 0.00	%) 35 0.28 0.00	0.00 8.3 50 0.29 0.01	0.00 10.1 70 0.30 0.01	0.04 12.6 90 0.31 0.02	0.11 14.9 120 0.32	0.20 17.3 240 0.40 0.14	0.30 20.0 400 0.51	0.82 0.44 24.1 800 0.69	0.62	0.7
Tilt Measurr Till Bandwid Tilt Anisopi. Residual Ce Residual At Induced Pla Non-Comm Residual Te TT Error Mar Total Ti Total Ti total Effect cotal Effect cotal Corresp	ement Error (one-assis) anatism Error (one-assis) anatism Error (one- troid Ansioplant and mospheric Dispersit to Sale Deformation Path In-Pittle Err pfTitt Error (if the Wavefroi Energy Energy	axis) axis) ism on ons ons ors tter (one-axi nt Erro Covera	z axis) is) r	2.42 0.74 3.60 0.55 0.68 0.00 0.11 0.77 2.00	mas	400 133 555 555 555 555 555 555 555 555 555	nm nm nm nm nm nm nm nm	18.6 16.7.1 46.8 20 20 20 3.2 mas/s Ti	mag (m Hz (-3d) arcsec to x reduc x reduc x reduc x reduc to x reduc to x reduc to x reduc to x reduc to x reduc to x reduc to y red	V) bb) from sci tion height tion Strel (mas 15 0.00	%) 35 0.28 0.00	0.00 8.3 50 0.29 0.01	0.00 10.1 70 0.30 0.01	0.04 12.6 90 0.31 0.02	0.11 14.9 120 0.32 0.04	0.20 17.3 240 0.40 0.14	0.30 20.0 400 0.51	0.82 0.44 24.1 800 0.69	0.62	0.7
Tilt Measurr Till Bandwid Tilt Anisopl. Residual Ce Residual At Induced Pia Non-Comm Residual Te TT Error Mar Total Ti otal Effect nsquared ky Covera Corresp sssumption	ement Error (one-a-se) in Error (one-a-se) anatism Error (one in Error (axis) axis) axis) axis) sism on on ons ors tter (one axi	z axis) is) r	2.42 0.74 3.60 0.55 0.68 0.00 0.11 0.77 2.00	mas mas mas mas mas mas mas mas mas taxel /	40 13 58 8 13 0 2 2 12 78 85 179 4perture	nm nm nm nm nm nm nm nm	18.6 16.7.1 46.8 20 20 20 3.2 mas/s Ti	mag (m Hz (-3d) arcsec to x reduc x reduc x reduc x reduc to x reduc to x reduc to x reduc to x reduc to x reduc to x reduc to y red	V) bb) from sci tion height tion Strel (mas 15 0.00	%) 35 0.28 0.00	0.00 8.3 50 0.29 0.01	0.00 10.1 70 0.30 0.01	0.04 12.6 90 0.31 0.02	0.11 14.9 120 0.32 0.04	0.20 17.3 240 0.40 0.14	0.30 20.0 400 0.51	0.82 0.44 24.1 800 0.69	0.62	0.7 41.
Tilt Measurr Tilt Bandwid Tilt Anisopl. Residual Ce Residual At Induced Pia Non-Comm Residual Te TT Error Mar Total Ti Total Ti cotal Effect cotal Corresp ssumption Atmospheri	ement Error (one-ass) anatism Error (one-bush) anatism Error (one tricid Anisoplant for fore tricid Anisoplant for some tricid Anisoplant for some tricid Anisoplant for some tricid Anisoplant to Escape Pointing II tricid tricid Anisoplant tricid t	axis) axis) axis) axis) axis ax	z z z z dege	2.42 0.74 3.60 0.55 0.68 0.00 0.11 0.77 2.00	mas mas mas mas mas mas mas mas mas taxel /	460 413 413 413 413 413 413 413 413 413 413	nm nm nm nm nm nm nm nm nm nm	18.6 16.7.1 46.8 20 20 20 3.2 mas/s 29 Til To FF Squ Seeing-	mag (m Hz (-3d) Hz (-3d) x reduc x reduc m conj Allocat Hz inpu Allocat Hz inpu MHM Mmas) mas Limited	V) bb) from sci tion tion height ion Strel (mas 15 0.00	%) 35 0.28 0.00	0.00 8.3 50 0.29 0.01	0.00 10.1 70 0.30 0.01 Total Eff	0.04 12.6 90 0.31 0.02	0.11 14.9 120 0.32 0.04	0.20 17.3 240 0.40 0.14	0.30 20.0 400 0.51	0.82 0.44 24.1 800 0.69 0.81	0.62	0.7 41. 37(0.5
Tilt Measurr Residual At Induced Pia Tilt Non-Comm Residual Te TI Terror Mar Total Ti Total Ti total Effect Corresp ssumption Atmosphere	ement Error (one-ass) anatism Error (one-in the	axis) axis) axis) axis) axis) axis a	z z sis) r z deg	2.42 0.74 3.60 0.55 0.68 0.00 0.11 0.77 2.00	mas mas mas mas mas mas mas mas mas taxel /	40 40 41 41 41 41 41 41 41 41 41 41 41 41 41	nm nm nm nm nm nm nm nm nm nm	18.6 16.7.1 46.8 20 20 20 3.2 mas/s 29 Til To FF Squ Seeing-	mag (m Hz (-3d) arcsec services arcsec service	V) bb) from sci tion tion height ion Strel (mas 15 0.00	%) 35 0.28 0.00	0.00 8.3 50 0.29 0.01 ed to the	0.00 10.1 70 0.30 0.01 Total Eff	0.04 12.6 90 0.31 0.02	0.11 14.9 120 0.32 0.04	0.20 17.3 240 0.40 0.14	0.30 20.0 400 0.51 0.34	0.82 0.44 24.1 800 0.69 0.81	0.62	0.7 41. 37(0.5
Tilt Measuri Tilt Measuri Tilt Measuri Tilt Measuri Tilt Anisopi Residual Ce Residual At Induced Pia Tilt Anisopi Residual Te TI TETO Mar Total Ti Total Ti Atmospheri Atmospheri	ement Error (one-ass) anatism Error (one-troid in Error (one-troid Ansiophania method Ans	axis) axis) axis) axis) ism on on ons ors ter (one core axis) core co	z z axis) r z deg m arcsec m/s	2.42 0.74 3.60 0.55 0.68 0.00 0.11 0.77 2.00	mas mas mas mas mas mas mas mas mas taxel /	404 133 585 585 585 585 585 585 585 585 585 5	nm n	18.6.2 16.7 46.8 20.8 20.0 0 0 0 3.2 mas/s To To F This fract	mag (m Hz (-3d) arcsec v reduce v reduc	V) b) b) to form sci tion tion height ion t distur ton Strel (mas 15 0.15 0.00	35 0.28 0.00	0.00 8.3 50 0.29 0.01 ed to the	0.00 10.1 70 0.30 0.01 Total Eff	0.04 12.6 90 0.31 0.02	0.11 14.9 120 0.32 0.04	0.20 17.3 240 0.40 0.14	0.30 20.0 400 0.51 0.34	0.82 0.44 24.1 800 0.69 0.81	0.62	0.7 41. 37 0.5
Tilt Measurr Tilt Measurr Tilt Bandwid Tilt Anisopl. Residual Ce Residual At Induced Pla Non-Comm Residual Te TT Error Mar Total Ti otal Effect ansquared Corresp Sssumption Atmospheri	ement Error (one-ass) anatism Error (one-troit of the Error (one troit of the Error (one troit of Anisophania morpheric Dispersite to Escape Pointing II grign Put The Filt Error (or tive Wavefror Energy Energy Grign Banding Sky Ondring Sky Ondring Sky Ondring Paracet Observing Paracet Observing Paracet Observing Paracet Wind Speed Outer Scale Wind Speed	axis) axis) axis) axis) axis) axis) axis) axis axis axis axis axis axis axis axis	z z age deg m arcsec m/s m m	2.42 d. 2.42 d	mas mas mas mas mas mas mas mas mas taxel /	46 46 13 3 4 4 4 5 4 5 4 5 6 6 6 6 6 6 6 6 6 6 6 6	nm n	18.6.2 16.7 46.8 20.8 20.0 0 0 0 3.2 mas/s To To F This fract	mag (m Hz (-3d) arcsec is a reduce x reduce x reduce x reduce x reduce x reduce x reduce hz in conjunt Allocatal Hz inpu Allocatal Hz inpu Allocatal String in conjunt in conjun	V) b) from sci tion from sci t	%) 35 0.28 0.00	0.00 8.3 50 0.29 0.01 ed to the	0.00 10.1 70 0.30 0.01 Total Eff	0.04 12.6 90 0.31 0.02	0.11 14.9 120 0.32 0.04	0.20 17.3 240 0.40 0.14	0.30 20.0 400 0.51 0.34	0.82 0.44 24.1 800 0.69 0.81	0.62	0.7 41. 37 0.5
Tilt Measurr Till Bandwid Tilt Anisopi. Residual Ce Residual At Induced Pia Non-Comm Residual Te TT Error Mar Total Ti otal Effect ansquared ky Covera Corresp Sssumption Atmospheri	ement Error (one-ass) anatism Error (one-to-ass)	axis) axis) axis) axis) axis) axis) axis) axis axis axis axis axis axis axis axis	z z axis) r z deg m arcsec m/s	2.42 d. 2.42 d	mas mas mas mas mas mas mas mas mas s mas s s s	46 46 13 36 56 56 56 56 56 56 56 56 56 56 56 56 56	nm n	18.6.1 16.7 16.7 16.7 16.7 16.7 16.7 16.7	mag (m Hz (-3d) arcsec is x reduced in x red	V) b) b) to form sci tion tion height ion t distur ton Strel (mas 15 0.15 0.00	35 0.28 0.00	0.00 8.3 50 0.29 0.01 LOWFS 19.6 Derived	0.00 10.1 70 0.30 0.01 Total Eff 18.9 Values HO WFS	0.04 12.6 90 0.31 0.02 fective W	0.11 14.9 120 0.32 0.04	0.20 17.3 240 0.40 0.14	0.30 20.0 400 0.51 0.34	0.82 0.44 24.1 800 0.69 0.81	0.62	0.7 41. 37 0.5
Tilt Measurr Tilt Measurr Tilt Measurr Tilt Bandwid Tilt Anisopl. Residual Ce Residual At Induced Pia Non-Comm Residual Te TT Error Mar Total Ti Total Ti cotal Effect Corresp ssumption Atmospheri	ement Error (one-ass) anatism Error (one-troid ansignature) anatism Error (one-troid ansignature) anatism Error (one-troid ansignature) and the Escape Pointing ill igning partition Path Ip-litt Error (of tive Wavefror) Energy Bege Dondling Sky ans / Parametet is/ Observing Parametet is/ Obs	covers Covers	z z age deg m arcsec m/s m m	2.42 d. 2.42 d	mas mas mas mas mas mas mas mas mas s mas s s s	46 4 13 3 4 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	nm n	18.6.1 16.7 16.7 16.7 16.7 16.7 16.7 16.7	mag (mag (mag (mag)) Hz (-3d) arcsec is x reduce m conj Allocata tal Str WHM Mag (-3d) arcsec	V) b) for form soil tion tion height form soil tion height form to the fight form to the fight form the fight f	35 0.28 0.00	0.00 8.3 50 0.29 0.01 LO WFS 19.6	0.00 10.1 70 0.30 0.01 Total Eff	0.04 12.6 90 0.31 0.02 fective W	0.11 14.9 120 0.32 0.04	0.20 17.3 240 0.40 0.14 16.8 951 57	0.30 20.0 400 0.51 0.34	0.82 0.44 24.1 800 0.69 0.81	0.62	0.7 41. 37 0.5
Tilt Measurr Tilt Bandwid Tilt Anisopi. Residual Ce Residual At Induced Pla Non-Comm Residual Te TT Error Mar Total Ti otal Effect cotal Effect Atmospheri Atmospheri AO Modes Ce	ement Error (one-ass) anatism Error (one-to-ass)	coveras Cov	z z axis) r z deg m arcsec m m/s m m/s x x 109 cm	2.42 d. 2.42 d	mas mas mas mas mas mas mas mas mas s mas s s s	46 46 13 36 56 56 56 56 56 56 56 56 56 56 56 56 56	nm n	18.6.1 16.7 16.7 16.7 16.7 16.7 16.7 16.7	mag (m Hz (-3d) arcsec to x reduce m conj Allocation of sk white m conj arcsec to the conj arcsec m conj arcsi arcsec m conj arc	V) b) from sci tion from sci t	35 0.28 0.00	0.00 8.3 50 0.29 0.01 LO WFS 19.6	0.00 10.1 70 0.30 0.01 Total Eff	0.04 12.6 90 0.31 0.02 fective W	0.11 14.9 120 0.32 0.04	0.20 17.3 240 0.40 0.14 16.8 951 57	0.30 20.0 400 0.51 0.34	0.82 0.44 24.1 800 0.69 0.81	0.62	0.7 41. 37 0.5
Tilt Measurr Tilt Bandwid Tilt Anisopi. Residual Ce Residual At Induced Pia Non-Comm Residual Te TT Error Mar Total Ti otal Effect ssumption Atmospheri AO Modes Ce	ement Error (one-ass) anatism Error (one-troit of the Error (one-troit of the Error (one-troit of Ansophant one-troit one-troit one-troit one-troit one-troit one-troit one-troit one-troit one-troit of Ansophant one-troit one	axis) axis) axis) axis) axis) axis) axis) axis axis axis axis axis axis axis axis	z z axis) r z deg m arcsec m m/s m m/s x x 109 cm	2.42 d. 2.42 d	mas mas mas mas mas mas mas mas mas s mas s s s	40 40 41 41 41 41 41 41 41 41 41 41 41 41 41	nm n	18.6.1 16.7 16.1 16.7 16.1 16.7 16.1 16.7 16.1 16.7 16.1 16.7 16.1 16.1	mag (mt le (-3d) arcsec to x reduce m conj al Allocat Hz input Allocat Hz	V) V) V) bb) room soi tion the light tion he light toon Strel (mass 15 0.15 0.00 y can b arcmin W using e-rms using e-rms	35 0.28 0.00	0.00 8.3 50 0.29 0.01 LO WFS 19.6	0.00 10.1 70 0.30 0.01 Total Eff	0.04 12.6 90 0.31 0.02 fective W	0.11 14.9 120 0.32 0.04	0.20 17.3 240 0.40 0.14 16.8 951 57	0.30 20.0 400 0.51 0.34	0.82 0.44 24.1 800 0.69 0.81	0.62	0.7 41. 37(0.5
Tilt Measurr Tilt Measurr Tilt Measurr Tilt Bandwid Tilt Anisople Residual Ce Residual At Induced Pia Non-Comm Residual Te TT Error Mar Total Ti Total Ti Corresp Ssumption Atmospheri AO Modes Ce Number of	ement Error (one-ass) anatism Error (one-troit of the Error (one troit of Association of the Error (one troit of Association or Path Tip-Tilt Error (or tive Wavefror) Energy Energy age Dondling Sky The Hard of Control of Control Tip-Tilt Error (or tive Wavefror) Energy Great of Control Tip-Tilt Error (or tive Wavefror) Energy Great of Control Tip-Tilt Error (or tive Wavefror) Energy Great of Control Tip-Tilt Error (or tive Wavefror) Energy Great of Control Tip-Tilt Error (or tive Wavefror) Energy Great of Control Tip-Tilt Error (or tive Wavefror) Energy Great of Control Tip-Tilt Error (or tive Wavefror) Energy Great of Control Tip-Tilt Error (or tive Wavefror) Energy Great of Control Tip-Tilt Error (or tive Wavefror) Energy Great of Control Tip-Tilt Error (or tive Wavefror) Energy Great of Control Tip-Tilt Error (or tive Wavefror) Energy Great of Control Tip-Tilt Error (or tive Wavefror) Energy Great of Control Tip-Tilt Error (or tive Wavefror) Energy Energy Great of Control Tip-Tilt Error (or tive Wavefror) Energy Energ	axis) axis) axis) axis) axis) axis) axis) axis axis axis axis axis axis axis axis	z z axis) r z deg m arcsec m m/s m m/s x x 109 cm	2.42 d. 2.42 d	mas mas mas mas mas mas mas mas mas s mas s s s	40 40 41 41 41 41 41 41 41 41 41 41 41 41 41	nm n	18.6.1 16.7 16.1 16.7 16.1 16.7 16.1 16.7 16.1 16.7 16.1 16.7 16.1 16.1	mag (mag (mag (mag (mag (mag (mag (mag (V) V) V) bb) room soi tion the light tion he light toon Strel (mass 15 0.15 0.00 y can b arcmin W using e-rms using e-rms	35 0.28 0.00	0.00 8.3 50 0.29 0.01 LO WFS 19.6	0.00 10.1 70 0.30 0.01 Total Eff	0.04 12.6 90 0.31 0.02 fective W	0.11 14.9 120 0.32 0.04	0.20 17.3 240 0.40 0.14 16.8 951 57	0.30 20.0 400 0.51 0.34	0.82 0.44 24.1 800 0.69 0.81	0.62	0.7 41.
Tilt Measurr Tilt Bandwid Tilt Anisopi. Residual Ce Residual At Induced Pia Non-Comm Residual Te TT Error Mar Total Ti Total Ti Corresp Ssumption Ad Modes Ce Number of	ement Error (one-ass) anatism Error (one-troid ansignature) anatism Error (one-troid ansignature) anatism Error (one-troid ansignature) and the Escape Pointing ii ii ging ii	axis) axis) axis) axis) axis) axis) axis) axis) axis axis axis axis axis axis axis axis	z z axis) r z deg m arcsec m m/s m m/s x x 109 cm	2.42 d. 2.42 d	mas mas mas mas mas mas mas mas mas saxel /	40 40 41 41 41 41 41 41 41 41 41 41 41 41 41	nm n	18.6.1 16.7 16.1 16.7 16.1 16.7 16.1 16.7 16.1 16.7 16.1 16.7 16.1 16.1	mag (mt le (-3d) arcsec to x reduce m conj al Allocat Hz input Allocat Hz	vy) bb) rom soi tion tion height ion Strel (mas 15 0.15 0.00 y can b arcmin w using e-ms Hz	35 0.28 0.00	0.00 8.3 50 0.29 0.01 LO WFS 19.6	0.00 10.1 70 0.30 0.01 Total Eff	0.04 12.6 90 0.31 0.02 fective W	0.11 14.9 120 0.32 0.04	0.20 17.3 240 0.40 0.14 16.8 951 57	0.30 20.0 400 0.51 0.34	0.82 0.44 24.1 800 0.69 0.81	0.62	0.7 41. 37(0.5

Io



QSO Host Galaxies

ptimizations/sky cov											COO	/ NG	AO I	PROP	KIE I	AKY			
Purpose:	This work	sheet wil	I allow one	to optio	mize sky cove erms; several	rage by	changing	parame	eters ells noi	nt to the	purple c	ells here							
					whether the s														
Solver Input Values	NGS	LGS			Current Sett	ings													
HO guide star brightness	LGS		mV		56	PDF/o	ubap/exp			Ontimiz	e LGS Of	f-Pointing	12	N					
Optim HO integration time:	0.00050		sec		958	Hz				Optimiz	e LGS Ra	ange Gat	e?	N					
Optim subaperture width: TT guide star brightness	0.174 LGS		meters mV			Subap mKs	S			Optimia	e Subap	Diamete	er?	N	0.182	m	Non-opti	m subap	width
TT integration time	0.00050	0.0005	sec		2000														
TT guide star distance TWFS guide star birghtness	LGS		arcsec mV																
TWFS integration time	0.0	0.0040	sec		249.75	Hz													
TWFS guide star search radius Number of laser beacons	0.0	4.0	arcsec																
LGS asterism radius	0.0	0.167	arcmin		Set ast rad =	0.001 f	or single L	GS		Optimia	e LGS as	terism r	adius?	N	< not	yet imple	mented (11/18/08)	
eck Wavefront Error	Budg	et Sur	mmary		Version 2.1									Scie	ence l	Band			
nde: NGAO LGS strument: DAVINCI										2 ()	u'	g' 0.47	r'	i'	Z	Y 4.00	J 1.25	1.64	2.2
Observation QSO Host Galaxie	8									λ (μμ) δλ (μμ)	0.36	0.14	0.62	0.75 0.15	0.88	1.03 0.12	0.16	0.29	0.3
										Δ (μασ)	6.7	8.8	11.6	14.1	16.6	19.4	23.5	30.8	41.
					Wavefr	ont								Stre	hl Rat	io (%)			
cience High-order Erro	rs (LG	S Mod	le)		Error (r			Paran	neter							(,,,			
Atmospheric Fitting Error Bandwidth Error						nm nm		Subaps Hz (-3d											
High-order Measurement Erro					64	nm	50	W											
LGS Tomography Error Asterism Deformation Error						nm nm		sci bea m LLT											
Chromatic Error					2	nm		Upper li	imit										
Dispersion Displacement Error Multispectral Error						nm nm	30	Estimat zen; sc											
Scintillation Error		Н			12	nm		Scint in	idex at 0).5um									
WFS Scintillation Error			113	nm	10	nm		Allocati											
Uncorrectable Static Telescope			-20			nm			cross Pu	ıpil									
Uncorrectable Dynamic Telesc Static WFS Zero-point Calibrat		ations				nm nm		Dekens Allocati											
Dynamic WFS Zero-point Calib Leaky Integrator Zero-point Ca	ration Erro	or 			25	nm		Allocati	on										
Stale Reconstructor Error	libration E	error				nm nm		Allocati Allocati											
Go-to Control Errors						nm		Allocati											
Residual Na Layer Focus Chang DM Finite Stroke Errors	е					nm nm		m/s Na um P-P	layer ve stroke	1									
DM Hysteresis					13	nm		from TN	AT mode	ı									
High-Order Aliasing Error DM Drive Digitization						nm nm		Subaps bits											
Uncorrectable AO System Abe					33	nm		Allocati											
Uncorrectable Instrument Abe DM-to-lenslet Misregistration						nm nm		DAVINO Allocati											
DM-to-lenslet Pupil Scale Erro						nm		Allocati	on										
Angular Anisoplanatism Error			92	nm	16	nm	1.0	arcsec											
HO Wavefront Error Margin						nm		Allocati	on										
Total High Order Wa	vefron	t Error	146	nm	154	nm	Hial	Ord	er St	rehl	0.00	0.01	0.09	0.20	0.31	0.43	0.56	0.71	0.8
							J												
cience Tip/Tilt Errors			Angu Error (Equiva WFE (r		1	Paran	neter					Streb	nl rati	os (%))		
		Sci Filter																	
Tilt Measurement Error (one-a Tilt Bandwidth Error (one-axis)	xis)			mas		nm nm		mag (m											
Tilt Anisoplanatism Error (one	-axis)			mas		nm	0.0	Hz (-3d arcsec	from sci										
Residual Centroid Anisoplanat		Н		mas		nm		x reduc											
Residual Atmospheric Dispers Induced Plate Scale Deformati	ons	"	0.00	mas mas	0	nm nm	0	x reduc m conj	height										
Non-Common-Path Tip-Tilt En Residual Telescope Pointing Ji		avie)		mas		nm nm	3.2 mas/	Allocat		han									
TT Error Margin	rei (oue-	akisj		mas		nm	29	Hz inpu Allocat		nance									
					40		<u> </u>		_		0.04	0.75	0.04	0.00	0.00	0.04	0.00	0.07	
Total Tip/Tilt Error (ne-ax	IS)	2.3	mas	42	nm		p/Tilt	Stre	hl	0.64	0.75	0.84	0.89	0.92	0.94	0.96	0.97	0.9
otal Effective Wavefron	it Erro	r			157	nm	То	tal St	rehl (%)	0.00	0.01	0.08	0.17	0.28	0.40	0.54	0.69	0.8
							F	WHM	(mas	5)	7.1	9.1	11.8	14.3	16.8	19.6	23.7	30.9	41.
			_														_		
nsquared Energy		н	Spa	axel/	Aperture	Diar	neter (15 0.13	35 0.46	50 0.62	70 0.71	90 0.72	0.73	240 0.76	400 0.80	800 0.86		0.5
isquareu Ellergy		н					Squ Seeing-		0.00	0.46	0.62			0.73					0.0
y Coverage			Galactic La	atitude	60	deg													
Corresponding Sky	Cover	age			0%		This fract	ion of sk	y can b	e correct	ted to the	Total Ef	fective W	/FE show	n				
	ers																		
	meters			System	Parameters						LO WFS	Magnitu	ides						
sumptions / Paramete		deg			LGS Asterisn		s		arcmin		1.0			-1.5	-1.8	-2.2	-2.7	-3.8	
Atmospheric / Observing Para Zenith Angle	30	111			BTO Transmir			50 0.60			Derived	l Values							
sumptions / Paramete	30 0.147	arcsec			HO WFS Trai	nsmissi	on	0.38		00111 -		HO WES			958	Hz			
Atmospheric / Observing Para Zenith Angle r0 theta0_eff Wind Speed	30 0.147 2.145 10.97	m/s						SH	using	CCID74		Detecte	a PDE/s	ubap/exp	56				
Atmospheric / Observing Para Zenith Angle r0 theta0_eff	30 0.147 2.145 10.97 50	m/s m	-2		HO WFS Typ			1.7	e- rms										
Atmospheric / Observing Para Zenith Angle nd theta0_eff Wind Speed Outer Scale Sodium Aburdance	30 0.147 2.145 10.97 50	m/s	-2		HO WFS Nois HO WFS Ant	ie i-aliasin		NO											
Atmospheric / Observing Para Zenith Angle 70 theta0_eff Wind Speed Outer Scale Sodium Abundance AO Modes of Operation	30 0.147 2.145 10.97 50 3	m/s m	-2		HO WFS Nois HO WFS Ant LO WFS Trans	ie I-aliasin smissic		NO 0.29		H2RG		LO WFS		ubap/exn	2000	Hz			
Atmospheric / Observing Para Zenith Angle no theta0_eff Wind Speed Outer Scale Sodium Aburdance	30 0.147 2.145 10.97 50 3	m/s m x 109 cm	-2		HO WFS Nois HO WFS Ant LO WFS Trans LO WFS Type LO WFS Nois	ie i-aliasin smissic e		NO 0.29 SH 3.2	using e- rms	H2RG				ubap/exp		Hz			
Atmospheric / Observing Para Zenth Angle 10 the 40 get Wind Speed Outer Scale Sodium Abundan AO Modes of Operation School Office AO Mode: LOWFS AO Mode:	30 0.147 2.145 10.97 50 3 MOAO Indep Pn:	m/s m x 109 cm	-2		HO WFS Nois HO WFS Ant LO WFS Trans LO WFS Type LO WFS Nois LO WFS Star	ie I-aliasin smissic e Type:	n In	NO 0.29 SH 3.2 M	using e- rms	H2RG				ubap/exp		Hz			
Atmospheric / Observing Para Atmospheric / Observing Para Zenith Angle 10 the abd. eff Wind Speed Outer Scale Sodum Aburdano Senez AO Mode: LOWFS AO Mode: Number Of WFS's for TI meass.	30 0.147 2.145 10.97 50 3 MOAO Indep Pn:	m/s m x 109 cm	-2		HO WFS Nois HO WFS Ant LO WFS Trans LO WFS Type LO WFS Nois LO WFS Star' Max TT Reject	ie I-aliasin smissio e Type: ttion Ba	n In	NO 0.29 SH 3.2	using e- rms	H2RG				ubap/exp		Hz			
Atmospheric / Observing Para Atmospheric / Observing Para Zenith Angle O Others / Observing Para Zenith Angle O Other Scale Outer Scale Sodium Abudance AO Modes of Operation Science AO Mode: LOWES AO Mode: Number of WRS's for TI meass	30 0.147 2.145 10.97 50 3 MOAO Indep Pn:	m/s m x 109 cm	-2	Observ	HO WFS Nois HO WFS Ant LO WFS Trans LO WFS Type LO WFS Nois LO WFS Star	ie i-aliasin smissic e Type: ttion Ba	n In	NO 0.29 SH 3.2 M 100	using e- rms	H2RG				ubap/exp		Hz			

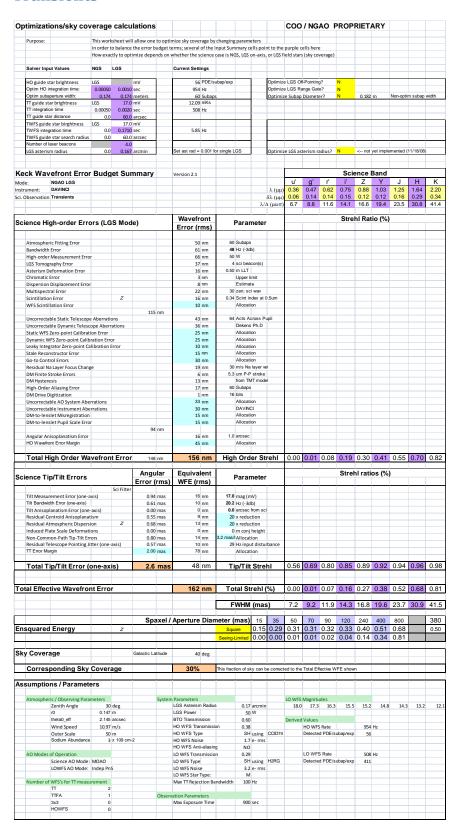
Gravitational Lensing

			llations								COO	/ NG	AO F	PROP	KIE I	AKY			
Purpose:	This work	sheet wil	I allow one	to optio	mize sky cove erms; several	rage by	changing	parame	eters ells noir	nt to the	purple c	ells here							
					whether the s														
Solver Input Values	NGS	LGS			Current Sett	ings													
HO guide star brightness	LGS		mV		67	PDF/o	ubap/exp			Ontimiza	LGS Of	L.Pointin	02	N					
Optim HO integration time:	0.00050		sec		949	Hz				Optimiz	e LGS Ra	ange Gat	e?	N					
Optim subaperture width: TT guide star brightness	0.174 LGS		meters mV		13.84	Subap mKs	S			Optimiz	e Subap	Diamete	er?	N	0.182	m	Non-opti	m subap	width
TT integration time	0.00050	0.0031	sec		324														
TT guide star distance TWFS guide star birghtness	LGS		arcsec mV																
TWFS integration time	0.0	5.6116	sec		0.18	Hz													
TWFS guide star search radius Number of laser beacons	0.0	45.3	arcsec				_								_				
LGS asterism radius	0.0	0.167	arcmin		Set ast rad =	0.001 f	or single L	.GS		Optimiz	e LGS as	terism ra	adius?	N	< not	yet imple	mented (11/18/08)	
eck Wavefront Error	Budg	et Sur	mmary		Version 2.1									Scie	ence l	Band			
nde: NGAO LGS										2 ()	u'	g' 0.47	r'	i'	Z	Y	J 1.25	1.64	2.2
trument: DAVINCI Observation Gravitational Lensi	sing									λ (μμ) δλ (μμ)	0.36	0.47	0.62 0.14	0.75 0.15	0.88	1.03 0.12	0.16	0.29	0.3
										(μασ)	6.7	8.8	11.6	14.1	16.6	19.4	23.5	30.8	41.
					Wavefr	ont								Stre	hl Rat	io (%)			
cience High-order Erro	rs (LG	S Mod	le)		Error (r			Parar	neter							(,,,			
								0.4											
Atmospheric Fitting Error Bandwidth Error						nm nm	47	Subaps Hz (-3d											
High-order Measurement Error	r				66	nm	50		non/a)										
LGS Tomography Error Asterism Deformation Error						nm nm		sci bea m LLT	LOTI(S)										
Chromatic Error					2	nm		Upper li											
Dispersion Displacement Error Multispectral Error						nm nm	30	Estimat zen; sc											
Scintillation Error		Н			12	nm		Scint in	dex at 0	.5um									
WFS Scintillation Error			115	nm	10	nm		Allocati											
Uncorrectable Static Telescope				L.		nm		Acts Ac		pil									
Uncorrectable Dynamic Telesco Static WFS Zero-point Calibration		ations				nm		Dekens Allocati											
Dynamic WFS Zero-point Calibr	ration Erro	or			25	nm		Allocati	on										
Leaky Integrator Zero-point Cal Stale Reconstructor Error	libration E	Error				nm nm		Allocati Allocati											
Go-to Control Errors					30	nm		Allocati	on										
Residual Na Layer Focus Change DM Finite Stroke Errors	;e					nm nm		m/s Na um P-P		I									
DM Hysteresis					13	nm		from TM	1T mode										
High-Order Aliasing Error DM Drive Digitization						nm nm		Subaps bits											
Uncorrectable AO System Aber					33	nm	16	Allocati											
Uncorrectable Instrument Aber						nm nm		DAVINO											
DM-to-lenslet Misregistration DM-to-lenslet Pupil Scale Error						nm		Allocati											
			100	nm			5.0	arcsec											
Angular Anisoplanatism Error HO Wavefront Error Margin						nm nm	5.0	Allocati	on										
Total High Order Way		4 F			474		16-1	n Ord	64		0.00	0.00	0.05	0.40	0.00	0.05	0.40	0.66	0.7
Total right Order wa	veiron	LEITOI	152	nm	171	nm	nıgı	loru	er Su	em	0.00	0.00	0.03	0.13	0.23	0.33	0.49	0.00	0.7
cience Tip/Tilt Errors			Angı	ılar	Equiva									Strel	al rati	os (%)			
							1 1	Paran	neter						au	(,,,	1		
		Sci Filter	Error (rms)	WFE (r	ms)	'	Parar	neter						ac	(,,,			
Tilt Measurement Error (one-ax	xis)	Sci Filter	2.22	mas	WFE (ri	nm	18.7	mag (m	iV)										
Tilt Measurement Error (one-ax Tilt Bandwidth Error (one-axis)		Sci Filter	2.22	mas	WFE (ri	nm nm	18.7 13.9	mag (m Hz (-3d	iV) b)							(,,,			
Tilt Measurement Error (one-a)	-axis)		2.22 0.88 3.48 0.55	mas mas mas mas	WFE (ri	nm nm nm	18.7 13.9 45.3 20	mag (m Hz (-3d arcsec x reduc	iV) b) from sci										
Tilt Measurement Error (one-a) Tilt Bandwidth Error (one-axis) Tilt Anisoplanatism Error (one- Residual Centroid Anisoplanati Residual Atmospheric Dispersi	-axis) tism ion	Sci Filter	2.22 0.88 3.48 0.55 0.26	mas mas mas mas mas	WFE (ri	nm nm nm nm	18.7 13.9 45.3 20	mag (m Hz (-3d arcsec x reduc x reduc	iV) b) from sci tion										
Tilt Measurement Error (one-aus) Till Bandwidth Error (one-aus) Tilt Anisoplanatism Error (one-Residual Centroid Anisoplanati Residual Atmospheric Dispersi Induced Plate Scale Deformatic Non-Common-Path Tip-Tilt Error	-axis) tism ion ons	Н	2.22 0.88 3.48 0.55 0.26 0.00	mas mas mas mas mas mas	WFE (ri	nm nm nm nm nm	18.7 13.9 45.3 20 20 0 3.2 mas/	mag (m Hz (-3d arcsec x reduc x reduc m conj	iV) b) from sci tion tion height ion										
Tilt Measurement Error (one-arii) Till Bandwidth Error (one-axis) Tilt Anisoplanatism Error (one- Residual Centroid Anisoplanati Residual Atmospheric Dispersi Induced Plate Scale Deformatic Non-Common-Path Tip-Tilt Err Residual Telescope Pointigr int	-axis) tism ion ons	Н	2.22 0.88 3.48 0.55 0.26 0.00 1.60 0.83	mas mas mas mas mas mas mas	WFE (ri	nm nm nm nm nm nm	18.7 13.9 45.3 20 20 0 3.2 mas/	mag (m Hz (-3d arcsec x reduc x reduc m conj Allocat Hz inpu	b) from sci tion tion height ion it distur	bance									
Tilt Measurement Error (one-aus) Till Bandwidth Error (one-aus) Tilt Anisoplanatism Error (one-Residual Centroid Anisoplanati Residual Atmospheric Dispersi Induced Plate Scale Deformatic Non-Common-Path Tip-Tilt Error	-axis) tism ion ons	Н	2.22 0.88 3.48 0.55 0.26 0.00 1.60 0.83	mas mas mas mas mas mas	WFE (ri	nm nm nm nm nm	18.7 13.9 45.3 20 20 0 3.2 mas/	mag (m Hz (-3d arcsec x reduc x reduc m conj	b) from sci tion tion height ion it distur	bance									
Tilt Measurement Error (one-arii) Tilt Bandwidth Error (one-axis) Tilt Anisoplanatism Error (one- Residual Centroid Anisoplanati Residual Atmospheric Dispersi Induced Plate Scale Deformatic Non-Common-Path Tip-Tilt Erro Residual Telescope Pointing It Residual Telescope Pointing It	-axis) tism ion ons rors tter (one-a	H axis)	2.22 0.88 3.48 0.55 0.26 0.00 1.60 0.83 2.00	mas mas mas mas mas mas mas	WFE (ri	nm nm nm nm nm nm	18.7 13.9 45.3 20 20 0 3.2 mas/ 29	mag (m Hz (-3d arcsec x reduc x reduc m conj Allocat Hz inpu	b) b) from sci tion tion height ion it distur		0.26	0.38	0.52	0.61				0.88	0.9
Tilt Measurement Error (one-axis) Tilt Bandwidth Error (one-axis) Tilt Anisoplanatism Error (one-Residual Centroid Anisoplanatism Error (one-Residual Centroid Anisoplanatism Error (one-Residual Atmospheric Dispersi Induced Plate Scale Deformatis Non-Common-Path Tijl-Tilt Error Pastidual Telescope Pointing Jit TT Error Margin	-axis) tism ion ons rors tter (one-a	H axis)	2.22 0.88 3.48 0.55 0.26 0.00 1.60 0.83 2.00	mas mas mas mas mas mas mas mas mas	WFE (ri	nm nm nm nm nm nm nm	18.7 13.9 45.3 20 20 0 3.2 mas/ 29	mag (m Hz (-3d arcsec x reduc x reduc m conj Allocat Hz inpu Allocat	b) b) from sci tion tion height ion it distur		0.26	0.38	0.52	0.61				0.88	0.9
Tilt Measurement Error (one-ass) Tilt Bandwidh Error (one-ass) Tilt Anisoplanatism Error (one-ass) Tilt Anisoplanatism Error (one-ass) Tilt Anisoplanatism Error (one-assidual Centrol Anisoplanati Residual Armospheric Dispersit Non-Common-Path Tip-Tilt Error Residual Telescope Pointing Jit TT Error Margin Total Tip/Tilt Error (c	-axis) tism tion ons rors tter (one-i	H axis)	2.22 0.88 3.48 0.55 0.26 0.00 1.60 0.83 2.00	mas mas mas mas mas mas mas mas mas	WFE (ri	nm nm nm nm nm nm nm nm	18.7 13.9 45.3 20 20 0 3.2 mas/ 29	mag (m Hz (-3d arcsec x reduc x reduc m conj Allocat Hz inpu Allocat	b) b) from scittion tition height ion tt disturt ion Strel	nl				0.61	0.69	0.75	0.82		
Tilt Measurement Error (one-ass) Tilt Bandwidth Error (one-ass) Tilt Ansoplanatism Error (one- Residual Centrol Ansoplanatis Residual Armospheric Dispersit Non-Common-Path Tip-Tilt Error Residual Telescope Pointing Jit TT Error Margin Total Tip/Tilt Error (c	-axis) tism tion ons rors tter (one-i	H axis)	2.22 0.88 3.48 0.55 0.26 0.00 1.60 0.83 2.00	mas mas mas mas mas mas mas mas mas	WFE (ri	nm nm nm nm nm nm nm nm	18.7 13.9 45.3 20 20 0 3.2 mas/ 29	mag (nr Hz (-3d arcsec x reduc x reduc m conj Allocat Hz inpu Allocat p/Tilt	b) b) from sci ction ction height ion st distur ion Strel	nl %)	0.00	0.00	0.03	0.08	0.69	0.75	0.82	0.58	0.7
Tilt Measurement Error (one-ass) Tilt Bandwidth Error (one-ass) Tilt Ansoplanatism Error (one- Residual Centrol Ansoplanatis Residual Armospheric Dispersit Non-Common-Path Tip-Tilt Error Residual Telescope Pointing Jit TT Error Margin Total Tip/Tilt Error (c	-axis) tism tion ons rors tter (one-i	H axis)	2.22 0.88 3.48 0.55 0.26 0.00 1.60 0.83 2.00	mas mas mas mas mas mas mas mas mas	WFE (ri	nm nm nm nm nm nm nm nm	18.7 13.9 45.3 20 20 0 3.2 mas/ 29	mag (m Hz (-3d arcsec x reduc x reduc m conj Allocat Hz inpu Allocat	b) b) from sci ction ction height ion st distur ion Strel	nl %)		0.00		0.08	0.69	0.75	0.82	0.58	0.7
Tilt Measurement Error (one-ass) Tilt Bandwidth Error (one-asis) Tilt Anisoplanatism Error (one- Residual Centrold Anisoplanatis Residual Atmospheric Dispersit Residual Atmospheric Dispersit Non-Common-Path Tip-Tilt Error Tilt Error Margin Total Tip/Tilt Error (c	-axis) tism tion ons rors tter (one-i	H axis) is)	2.22 0.88 3.48 0.55 0.26 0.00 1.60 0.83 2.00	mas mas mas mas mas mas mas mas	WFE (ri	nm nm nm nm nm nm nm nm	18.7 13.9 45.3 20 20 0 3.2 mas/ 29	mag (m Hz (-3d arcsec x reduc x reduc m conj Allocat Hz inpu Allocat p/T ilt	NV) bb) inform sci inf	%) 35	0.00 8.4 50	0.00	0.03	0.08 14.9	0.69 0.16 17.4	0.75 0.26 20.1	0.82 0.40 24.1 800	0.58	0.7
Tilt Measurement Error (one-axis) Tilt Bandwidth Error (one-axis) Tilt Anisoplanatism Error (one-axis) Tilt Anisoplanatism Error (one-Residual Centroid Anisoplanati Residual Atmospheric Dispersi Induced Plate Scale Deformati Non-Common-Path Tip-Tilt Error Residual Telescope Pointing Jit TT Error Margin Total Tip/Tilt Error (c	-axis) tism tion ons rors tter (one-i	H axis)	2.22 0.88 3.48 0.55 0.26 0.00 1.60 0.83 2.00	mas mas mas mas mas mas mas mas	WFE (ri	nm nm nm nm nm nm nm nm	18.7 13.9 45.3 20 0 3.2 mas/ 29 Ti To F	mag (m Hz (-3d arcsec x reduce x reduce m conj Allocat Hz inpu Allocat p/Tilt tal St WHM	IV) bb) from sci from	%) 35 0.43	0.00 8.4 50 0.58	0.00 10.1 70 0.65	0.03 12.7 90 0.67	0.08 14.9 120 0.68	0.69 0.16 17.4 240 0.72	0.75 0.26 20.1 400 0.78	0.82 0.40 24.1 800 0.86	0.58	0.7
Tilt Measurement Error (one-axis) Tilt Bandwidth Error (one-axis) Tilt Anisoplanatism Error (one-axis) Tilt Anisoplanatism Error (one-Residual Centroid Anisoplanati Residual Atmospheric Dispersi Induced Plate Scale Deformati Non-Common-Path Tip-Tilt Error Residual Telescope Pointing Jit TT Error Margin Total Tip/Tilt Error (c	-axis) tism tion ons rors tter (one-i	H axis) is)	2.22 0.88 3.48 0.55 0.26 0.00 1.60 0.83 2.00	mas mas mas mas mas mas mas mas	WFE (ri	nm nm nm nm nm nm nm nm	18.7 13.9 45.3 20 20 0 3.2 mas/ 29	mag (m Hz (-3d arcsec x reduce x reduce m conj Allocat Hz inpu Allocat p/Tilt tal St WHM	NV) bb) inform sci inf	%) 35	0.00 8.4 50	0.00 10.1 70 0.65	0.03 12.7 90 0.67	0.08 14.9	0.69 0.16 17.4 240 0.72	0.75 0.26 20.1 400 0.78	0.82 0.40 24.1 800 0.86	0.58	0.9 0.7 41. 36 0.5
Tilt Measurement Error (one-ass) Tilt Bandwidth Error (one-ass) Tilt Ansoplanatism Error (one-ass) Tilt Ansoplanatism Error (one-ass) Tilt Ansoplanatism Error (one-ass) Tilt Ansoplanatism Error (one-ass) Residual Almospheric Dispersit Non-Common-Path Tip-Tilt Error Residual Telescope Pointing Jit TT Error Margin Total Tip/Tilt Error (c) tall Effective Wavefron squared Energy	-axis) tism tion ons rors tter (one-i	H axis) is)	2.22 0.88 3.48 0.55 0.26 0.00 1.60 0.83 2.00	mas	WFE (ri 38 15 59 9 5 0 27 144 145 92 192 Aperture	nm nm nm nm nm nm nm nm	18.7 13.9 45.3 20 0 3.2 mas/ 29 Ti To F	mag (m Hz (-3d arcsec x reduce x reduce m conj Allocat Hz inpu Allocat p/Tilt tal St WHM	IV) bb) from sci from	%) 35 0.43	0.00 8.4 50 0.58	0.00 10.1 70 0.65	0.03 12.7 90 0.67	0.08 14.9 120 0.68	0.69 0.16 17.4 240 0.72	0.75 0.26 20.1 400 0.78	0.82 0.40 24.1 800 0.86	0.58	0.7
Tilt Measurement Error (one-asi) Tilt Anisoplanatism Error (one-asis) Tilt Anisoplanatism Error (one-asis) Tilt Anisoplanatism Error (one-asis) Tilt Anisoplanatism Error (one-asisdual Centrol Anisoplanati Residual Almospheric Dispersit Residual Almospheric Dispersit The Error Almospheric Dispersit TT Error Margin Total Tip/Tilt Error (cr Total Tip/Tilt Error (cr Stall Effective Wavefron squared Energy	-axis) isism ion ons ons tter (one one-axi	н axis) is) r	2.222 0.88 3.48 0.55 0.226 0.000 1.60 0.83 2.000 5.00	mas	WFE (ri 388 155 99 9 5 07 27 144 145 92 192 Aperture	nm nm nm nm nm nm nm nm	18.7 13.9 45.3 20 20 3.2 mas/s Ti To	mag (m Hz (-3d arcsec x reduc m conj Allocat Hz inpu Allocat D/Tilt tal St WHM mas)	strein (mass)	%) 35 0.43 0.00	0.00 8.4 50 0.58 0.01	0.00 10.1 70 0.65 0.02	0.03 12.7 90 0.67 0.03	0.08 14.9 120 0.68 0.05	0.69 0.16 17.4 240 0.72 0.18	0.75 0.26 20.1 400 0.78	0.82 0.40 24.1 800 0.86	0.58	0.7
Tilt Measurement Error (one-ass) Tilt Bandwidth Error (one-ass) Tilt Anisoplanatism Error (one-ass) Tilt Anisoplanatism Error (one-ass) Tilt Anisoplanatism Error (one-ass) Tilt Anisoplanatism Error (one-ass) Residual Armospheric Dispersit Non-Common-Path Tip-Tilt Error Non-Common-Path Tip-Tilt Error (or Total Tip/Tilt Error (or tal Effective Wavefron Effective Wavefron squared Energy	-axis) isism ion ons ons tter (one one-axi	н axis) is) r	2.222 0.88 3.48 0.55 0.226 0.000 1.60 0.83 2.000 5.00	mas	WFE (ri 38 15 59 9 5 0 27 144 145 92 192 Aperture	nm nm nm nm nm nm nm nm	18.7 13.9 45.3 20 20 3.2 mas/s Ti To	mag (m Hz (-3d arcsec x reduc m conj Allocat Hz inpu Allocat D/Tilt tal St WHM mas)	strein (mass)	%) 35 0.43 0.00	0.00 8.4 50 0.58 0.01	0.00 10.1 70 0.65 0.02	0.03 12.7 90 0.67 0.03	0.08 14.9 120 0.68	0.69 0.16 17.4 240 0.72 0.18	0.75 0.26 20.1 400 0.78	0.82 0.40 24.1 800 0.86	0.58	0.7
Tilt Measurement Error (one-axis) Tilt Anisoplanatism Error (one-axis) Tilt Anisoplanatism Error (one-axis) Tilt Anisoplanatism Error (one-axis) Tilt Anisoplanatism Error (one-axis) Residual Armospheric Dispersit Residual Armospheric Dispersit The Experiment of the Common Path Tip-Tilt Error Margin Total Tip/Tilt Error (or Datal Effective Wavefron	-axis) isism ion ons ons ors tter (one-axi ont Error	н axis) is) r	2.222 0.88 3.48 0.55 0.226 0.000 1.60 0.83 2.000 5.00	mas	WFE (ri 388 155 99 9 5 07 27 144 145 92 192 Aperture	nm nm nm nm nm nm nm nm	18.7 13.9 45.3 20 20 3.2 mas/s Ti To	mag (m Hz (-3d arcsec x reduc m conj Allocat Hz inpu Allocat D/Tilt tal St WHM mas)	strein (mass)	%) 35 0.43 0.00	0.00 8.4 50 0.58 0.01	0.00 10.1 70 0.65 0.02	0.03 12.7 90 0.67 0.03	0.08 14.9 120 0.68 0.05	0.69 0.16 17.4 240 0.72 0.18	0.75 0.26 20.1 400 0.78	0.82 0.40 24.1 800 0.86	0.58	0.7
Tilt Measurement Error (one-axis) Tilt Anisoplanatism Error (one-axis) Residual Almospheric Dispersit Residual Almospheric Dispersit Till Error Margin Total Tip/Tilt Error (or total Tip/Tilt Error (-axis) issm ion ons ons ors tter (one-axi ont Error Covera	н axis) is) r	2.222 0.88 3.48 0.55 0.226 0.000 1.60 0.83 2.000 5.00	mas	WFE (ri 38 15 59 9 5 0 0 27 144 145 92 192 Aperture 60 30%	nm nm nm nm nm nm nm nm	18.7 13.9 45.3 20 20 3.2 mas/s Ti To	mag (m Hz (-3d arcsec x reduc m conj Allocat Hz inpu Allocat D/Tilt tal St WHM mas)	strein (mass)	%) 35 0.43 0.00	0.00 8.4 50 0.58 0.01	0.00 10.1 70 0.65 0.02	0.03 12.7 90 0.67 0.03	0.08 14.9 120 0.68 0.05	0.69 0.16 17.4 240 0.72 0.18	0.75 0.26 20.1 400 0.78	0.82 0.40 24.1 800 0.86	0.58	0.7
Tilt Measurement Error (one-aus) Tilt Anisoplanatism Erro (one-aus) Tilt Anisoplanatism Error (one-aus) Tilt Anisoplanatism Error (one-aus) Tilt Anisoplanatism Error (one-aus) Tilt Anisoplanatism Error (one-aus) Residual Almospheric Dispersit Non-Common-Path Tip-Tilt Error Non-Common-Path Tip-Tilt Error (or Tip-Tilt	axis) issm ion ion ons ons ons tter (one-axi tterroi Covera Covera 30	H H axis)	2.222 0.88 3.48 0.55 0.226 0.000 1.60 0.83 2.000 5.00	mas	### WFE (ri ### 38 ### 38 ### 15 ### 59 ### 9 ### 145 ### 145 ### 192 ### 192 ### Aperture ### 60 ### 30% ### 145 #### 145 #### 145 ### 145 #### 145 ### 145 ### 145 ### 145 #### 145 #### 145 ###### 145 #### 145 #	nm n	18.7.1 13.9 45.3 20.3 0 0 0 0 3.2 mas/s Ti To F Tous seeing-1	mag (m Hz (-3d as	bb) bb) bb) bb) cttion tition height ion tt distur ion Strel (mas 15 0.12 0.00	%) 35 0.43 0.00	0.00 8.4 50 0.58 0.01	0.00 10.1 70 0.65 0.02 Total Ef	0.03 12.7 90 0.67 0.03	0.08 14.9 120 0.68 0.05	0.69 0.16 17.4 240 0.72 0.18	0.75 0.26 20.1 400 0.78 0.42	0.82 0.40 24.1 800 0.86	31.2	0.7 411 36 0.5
Tilt Measurement Error (one-aus) Tilt Bandwidth Error (one-aus) Tilt Anisophantism Error (one- Bestidual Centrol Anisophantism Error (one- Bestidual Centrol Anisophantism Error (one- Bestidual Centrol Anisophantism Error (one- Tilt Anisophantism Error (one- Tilt Error Margin Total Tip/Tilt Error (c tall Effective Wavefron squared Energy y Coverage Corresponding Sky (Sumptions / Paramete Atmospheric / Observing Paramete	axis)	H axis) r H age	2.222 0.88 3.48 0.55 0.226 0.000 1.60 0.83 2.000 5.00	mas	### WFE (ri ### 38 ### 38 ### 15 ### 38 #	nm nm nm nm nm nm nm nm nm	18.7.1 13.9 45.3 20.3 0 0 0 0 3.2 mas/s Ti To F Tous seeing-1	mag (m Hz (-3d arcsec x reduc x reduc x reduc x reduc x reduc x reduc the first reduce the	VV) bb) bb) tripe in the property of the prope	%) 35 0.43 0.00	0.00 8.4 50 0.58 0.01 ed to the	0.00 10.1 70 0.65 0.02 Total Ef	0.03 12.7 90 0.67 0.03 fective W	0.08 14.9 120 0.68 0.05	0.69 0.16 17.4 240 0.72 0.18	0.75 0.26 20.1 400 0.78 0.42	0.82 0.40 24.1 800 0.86 0.38	31.2	0.7 411 36 0.5
Tilt Measurement Error (one-axis) Tilt Anisoplanatism Error (one-axis) Residual Almospheric Dispersit Residual Almospheric Dispersit Till Error Margin Total Tip/Tilt Error (cr total Tip/Tilt Error (axis)	H axis) r H age deg m m arcsec	2.222 0.88 3.48 0.55 0.226 0.000 1.60 0.83 2.000 5.00	mas	### WFE (ri ### 38 ### 38 ### 15 ### 59 ### 9 ### 145 ### 145 ### 192 ### 192 ### Aperture ### 60 ### 30% ### 145 #### 145 #### 145 ### 145 #### 145 ### 145 ### 145 ### 145 #### 145 #### 145 ###### 145 #### 145 #	nm nm nm nm nm nm nm nm nm nm	18.7:13.9 43.3 20.3 20.3 20.3 3.2 mas/s 29 Ti To F Squ Seeing-	mag (m Hz (-3d as	VV) bb) bb) tripe in the property of the prope	%) 35 0.43 0.00	0.00 8.4 50 0.58 0.01	0.00 10.1 70 0.65 0.02 Total Ef	0.03 12.7 90 0.67 0.03	0.08 14.9 120 0.68 0.05	0.69 0.16 17.4 240 0.72 0.18	0.75 0.26 20.1 400 0.78 0.42	0.82 0.40 24.1 800 0.86 0.38	31.2	0.7 411 36 0.5
Tilt Measurement Error (one-axis) Tilt Anisoplanatism Error (one-axis) Residual Almospheric Dispersit Residual Almospheric Dispersit Till Error Margin Total Tip/Tilt Error (or Till	axis)	H axis) r H age deg m arssec m/s m	2 222 0.88 3.44 48 3.44 48 3.45 48 3.45 48 3.45 3.45 3.45 3.45 3.45 3.45 3.45 3.45	mas	### WFE (ri ### 38 #	nm n	18.7:13.9 43.3 20.3 20.3 20.3 3.2 mas/s 29 Ti To F Squ Seeing-	mag (m Hz (-3d) marcsec x reduce x reduce x reduce x reduce x reduce x reduce the interest of	vy can b	%) 35 0.43 0.00	0.00 8.4 50 0.58 0.01 ed to the	0.00 10.1 70 0.65 0.02 Total Et	90 0.67 0.03	0.08 14.9 120 0.68 0.05	0.69 0.16 17.4 240 0.72 0.18	0.75 0.26 20.1 400 0.78 0.42	0.82 0.40 24.1 800 0.86 0.38	31.2	0.7 41 36 0.5
Tilt Measurement Error (one-as- Till Bandwidn Error (one-aws) Till Anisoplanatism Error (one- sersidual Centrol Anisoplanatism Error (one- till Error Mangin Total Tip/Tilt Error (c Till Error (c Stall Effective Wavefron Stall Effective Wavefron Esquared Energy Ly Coverage Corresponding Sky (Sumptions / Paramete Atmospheric / Observing Paramete	axis)	H axis) r H deg m m arcsec m/s	2 222 0.88 3.44 48 3.44 48 3.45 48 3.45 48 3.45 3.45 3.45 3.45 3.45 3.45 3.45 3.45	mas	### WFE (ri ### 38 ### 38 ### 15 ### 59 ### 50 #	nm nm nm nm nm nm nm nm nm nm nm nm	18.7.1 13.9.4 145.3.2 20.3.2 20.3.2.1 20.3.2.2 29 Till To FF Squ Seeing-1	mag (m Hz (-3d) marcsec x reduce x reduce x reduce x reduce x reduce x reduce the interest of	VV) b) b) b) for comparison of the comparison of	35 0.43 0.00	0.00 8.4 50 0.58 0.01 ed to the	0.00 10.1 70 0.65 0.02 Total Et	90 0.67 0.03	0.08 14.9 120 0.68 0.05	0.69 0.16 17.4 240 0.72 0.18	0.75 0.26 20.1 400 0.78 0.42	0.82 0.40 24.1 800 0.86 0.38	31.2	0.7 41 36 0.5
Tilt Measurement Error (one-artiti Bandwidh Error (one-axis) Tilt Anisoplanatism Error (one-axis) Tilt Anisoplanatism Error (one-Residual Centroid Anisoplanatism Error (one-Residual Centroid Anisoplanatism Error (one-Residual Televical Anisoplanatism Error (one-Residual Televica) Total Tip/Tilt Error (one-article) Total Tip/Tilt Error (one-article) Total Tip/Tilt Error (one-article) Total Tip/Tilt Error (one-article) Total Effective Wavefron Stall Effective Wavefron Corresponding Sky (one-article) Total Tip/Tilt Error (one-article) Total Effective Wavefron Sumptions / Paramete Atmospheric / Observing Parame	-axis) -a	H axis) r H age deg m arssec m/s m	2 222 0.88 3.44 48 3.44 48 3.45 48 3.45 48 3.45 3.45 3.45 3.45 3.45 3.45 3.45 3.45	mas	### WFE (ri ### 38 #	nm n	18.7:13.9:45.3 20.3 20.2 20 20 3.2 mas/s To F To F This fract	mag (nr la	wy) yv) yv) bb) ctorer sci tion height ion Strel (mass 15 0.12 0.00 arcmin W using e-rms	35 0.43 0.00	0.00 8.4 50 0.58 0.01 ed to the	0.00 10.1 70 0.65 0.02 Total Et	0.03 12.7 90 0.67 0.03 fective W	0.08 14.9 120 0.68 0.05	0.69 0.16 17.4 240 0.72 0.18 16.9 949 57	0.75 0.26 20.1 400 0.78 0.42	0.82 0.40 24.1 800 0.86 0.38	31.2	0.7 411 36 0.5
Tilt Measurement Error (one-artill Bandwidth Error (one-axis) Tilt Anisoplanatism Error (one-axis) Tilt Anisoplanatism Error (one-axis) Tilt Anisoplanatism Error (one-axis) Tilt Anisoplanatism Error (one-axis) Residual Terror (one-axis) Total Tip/Tilt Error (one-axis) Total Effective Wavefron Stall Effective Wavefron One-axis one	axis)	H axis) If H age deg m arcsec m/s x 109 cm-	2 222 0.88 3.44 48 3.44 48 3.45 48 3.45 48 3.45 3.45 3.45 3.45 3.45 3.45 3.45 3.45	mas	### WFE (ri ### 183 ### 185 #### 185 ### ### 185 ### ###### ####### ########## ########	nm n	18.7:13.9:45.3 20.3 20.2 20 20 3.2 mas/s To F To F This fract	mag (m Hz (-3d arcsec x reduce m con) Allocat tal St tal S	VV) bb) bb) bb) bb) bb) bb) bb) bb) bb) bb	35 0.43 0.00	0.00 8.4 50 0.58 0.01 ed to the	0.00 10.1 70 0.65 0.02 Total Et	0.03 12.7 90 0.67 0.03 fective W	0.08 14.9 120 0.68 0.05	0.69 0.16 17.4 240 0.72 0.18 16.9 949 57	0.75 0.26 20.1 400 0.78 0.42	0.82 0.40 24.1 800 0.86 0.38	31.2	0.7 411 36 0.5
Tilt Measurement Error (one-artill Bandwidth Error (one-axis) Tilt Anisoplanatism Error (one-axis) Tilt Anisoplanatism Error (one-axis) Tilt Anisoplanatism Error (one-axis) Tilt Anisoplanatism Error (one-axis) Residual Terror (one-axis) Non-Common-Path Tip-Tilt Error (ore-axis) Total Tip/Tilt Error (ore-axis) Total Tip/Tilt Error (ore-axis) Total Tip/Tilt Error (ore-axis) Total Tip/Tilt Error (ore-axis) Total Effective Wavefron Datal Effective Wavefron Saquared Energy Corresponding Sky Saumptions / Paramete Atmospheric / Observing Paran Total Tip/Tilt Error (ore-axis) Saumptions / Paramete Atmospheric / Observing Paran Total Error (one-axis) Title Error (one-axis) Title Error (one-axis) Total Tip/Tilt Error (ore-axis) Title Error (ore-axis) Total Tip/Tilt Error (ore-axis) Title Error	axis) sism ion ons ons ter (one-axi one-axi on	H axis) If H age deg m arcsec m/s x 109 cm-	2 222 0.88 3.44 48 3.44 48 3.45 48 3.45 48 3.45 3.45 3.45 3.45 3.45 3.45 3.45 3.45	mas	### WFE (ri ### 183 #### 183 ### ### 183 #### ##### ###### ######## ######## ####	nm n	18.7.1 13.9.4 45.3.2 20.2 20.2 20.3.2 mas/s Ti To F This fract This fract	mag (mr mag) (mr mag) (mr mag) (mr mr m	wy bb) from soi tition tition height don he	35 0.43 0.00	0.00 8.4 50 0.58 0.01 ed to the	0.00 10.1 70 0.65 0.02 Total Et	0.03 12.7 90 0.67 0.03 fective W	0.08 14.9 120 0.68 0.05	0.69 0.16 17.4 240 0.72 0.18 16.9 949 57	0.75 0.26 20.1 400 0.78 0.42	0.82 0.40 24.1 800 0.86 0.38	31.2	0.7 411 36 0.5
Tilt Measurement Error (one-artilt Bandwidh Error (one-axis) Tilt Anisoplanatism Error (one-axis) Tilt Anisoplanatism Error (one-axis) Tilt Anisoplanatism Error (one-Residual Centroid Anisoplanatism Error (one-axis) Residual Terror (one-axis) Total Tip/Tilt Error (one-axis) Total Tip/Tilt Error (one-axis) Total Tip/Tilt Error (one-axis) Total Tip/Tilt Error (one-axis) Total Effective Wavefron	axis) sism sion ons ors tetr (one-axi one-axi	H H age deg m arcsec m/s x 109 cm- s	2 222 0.88 3.44 48 3.44 48 3.45 48 3.45 48 3.45 3.45 3.45 3.45 3.45 3.45 3.45 3.45	mas	### WFE (ri ### 38 #	nm n	18.7.1 13.9.4 45.3.2 20.2 20.2 20.3.2 mas/s Ti To F This fract This fract	mag (mt la	wy bb) from soi tition tition height ion height ion from Strel Strel (mas 15 0.12 0.00 arcmin W using e-rms using e-rms	35 0.43 0.00	0.00 8.4 50 0.58 0.01 ed to the	0.00 10.1 70 0.65 0.02 Total Et	0.03 12.7 90 0.67 0.03 fective W	0.08 14.9 120 0.68 0.05	0.69 0.16 17.4 240 0.72 0.18 16.9 949 57	0.75 0.26 20.1 400 0.78 0.42	0.82 0.40 24.1 800 0.86 0.38	31.2	0.7
Tilt Measurement Error (one-asi) Tilt Anisoplanatism Error (one-asis) Residual Almospheric Dispersit Residual Telescape Pointing II TE Error Margin Total Tip/Tilt Error (c total Tip/Tilt Error (axis) sism ion ons ons ter (one-axi one-axi on	H axis) F deg m arcsec m/s m x 109 cm	2 222 0.88 3.44 48 3.44 48 3.45 48 3.45 48 3.45 3.45 3.45 3.45 3.45 3.45 3.45 3.45	mas mas mas mas mas mas mas mas sel /	### WFE (ri ### 183 #### 183 ### ### 183 #### ##### ###### ######## ######## ####	nm n	18.7.1 13.9.4 45.3.2 20.2 20.2 20.3.2 mas/s Ti To F This fract This fract	mag (mr mag) (mr mag) (mr mag) (mr mr m	wy) b) b) from sci tion tion height ion tt distur ton tt distur ton tt distur ton tt distur ton tt distur	35 0.43 0.00	0.00 8.4 50 0.58 0.01 ed to the	0.00 10.1 70 0.65 0.02 Total Et	0.03 12.7 90 0.67 0.03 fective W	0.08 14.9 120 0.68 0.05	0.69 0.16 17.4 240 0.72 0.18 16.9 949 57	0.75 0.26 20.1 400 0.78 0.42	0.82 0.40 24.1 800 0.86 0.38	31.2	0.7 411 36 0.5

Astrometry Science

0	ions/sky cov				onti- '	sela:-	rae:	ch '		sto		COO								
Purpose:		in order	to balance	II allow one to the error but	lget term	s; several	of the	Input Sun	nmary o	ells poir										
		How exa	ctly to opt	timize depend	s on whe	ther the s	cience	case is N	GS, LGS	on-axis,	or LGS f	ield stars	(sky co	verage)						
Solver Inp	out Values	NGS	LGS		Cu	rrent Sett	ings													
HO guide	star brightness	LGS		mV		57	PDF/s	ubap/exp			Ontimiz	e LGS Of	f-Pointin	n?	N					
Optim HO	integration time:	0.00050		sec		948	Hz				Optimiz	e LGS Ra	ange Gat	e?	N					
Optim sub	aperture width: tar brightness	0.174 LGS		meters mV	_		Subap mKs	5			Optimi	ze Subap	Diamete	er?	N	0.182	m	Non-opti	m subap	width
TT integrat	ion time	0.00050	0.0045	sec			Hz													
	tar distance le star birghtness	LGS		arcsec mV	_															
	gration time	0.0				0.22	Hz													
TWFS guid Number of	le star search radius laser beacons	0.0	42.4	arcsec	_															_
LGS asteri		0.0		arcmin	Set	ast rad =	0.001 f	or single L	.GS		Optimia	ze LGS as	terism ra	adius?	N	< not	yet impl	emented (11/18/08)
Keck Way	vefront Error	Budo	et Su	mmarv	Ve	rsion 2.1									Sci	ence	Band			
Aode:	NGAO LGS											u'	g'	ď	i'	Z		J	Н	K
nstrument:	DAVINCI	_			_						λ (μμ)		0.47	0.62	0.75 0.15	0.88	1.03	1.25 0.16	1.64 0.29	0.34
ci. Observatio	Astrometry Science	e									δλ (μμ) Δ (μασ)	6.7	8.8			16.6	0.12 19.4		30.8	
Science H	igh-order Erro	ors (LG	S Mod	ie)		Navefr rror (r			Parar	neter					Stre	hl Rat	tio (%)		
						.,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,	IIIS													
	ric Fitting Error						nm nm		Subaps											
Bandwidtl High-orde	n Error r Measurement Erro	r					nm nm		Hz (-3d	-)										
LGS Tomo	graphy Error						nm	4	sci bea	con(s)										
Asterism I Chromatic	Deformation Error Error						nm nm		m LLT Upper I											
Dispersion	n Displacement Error					2	nm		Estima	e										
Multispec Scintillation			Н				nm nm		zen; so Scint in		5µm									
	Illation Error						nm nm	0.34	Allocati		Juli									
				115 n	m		nm		Acts A	mac P	mil									
	able Static Telescopi able Dynamic Telesc						nm nm	64	Dekens	Ph.D	ą.m									
Static WFS	Zero-point Calibrat	ion Error				25	nm		Allocati											
	VFS Zero-point Calib grator Zero-point Ca						nm nm		Allocati											
Stale Reco	instructor Error					15	nm		Allocati	on										
Go-to Con Residual N	trol Errors la Layer Focus Chans	7P					nm nm	30	Allocati m/s Na		1									
DM Finite	Stroke Errors	-				6	nm		um P-P	stroke										
DM Hyster	resis					13	nm		from TM Subaps		ı									
	r Aliasing Error Digitization						nm nm		Subaps											
Uncorrect	able AO System Abe						nm		Allocati											
	able Instrument Abe Islet Misregistration						nm nm		Allocati											
	islet Pupil Scale Erro						nm		Allocati											
				101 n																
American A	alamatan Casa			101 11	m	-		5.0												
	nisoplanatism Error ont Error Margin			10111	m		nm nm	5.0	arcsec Allocati	on										
HO Wavefr	ont Error Margin	votron	t Error			45	nm		arcsec Allocati		rabi	0.00	0.00	0.05	0.12	0.22	0.25	0.40	0.66	0.70
HO Wavefr		vefron	t Erroi			45			arcsec		rehl	0.00	0.00	0.05	0.13	0.23	0.35	0.49	0.66	0.79
Total F	ont Error Margin ligh Order Wa	vefron	t Error	153 n	n E	45 171 Equiva	nm nm lent	Higl	arcsec Allocati	er St		0.00	0.00	0.05		0.23 hI rati			0.66	0.79
Total F	ont Error Margin	vefron		153 n	n E	45 171	nm nm lent	Higl	arcsec Allocati	er St		0.00	0.00	0.05					0.66	0.79
Total F	ont Error Margin ligh Order Wa		t Error	153 n	nr E	171 Equiva WFE (r	nm lent ms)	Higl	arcsec Allocati	er St		0.00	0.00	0.05					0.66	0.79
Total F Science T Tilt Measu	ip/Tilt Errors prement Error (one-addith Error (one-addith Error (one-axis)	ixis)		Angula Error (ri	n Ens) \	171 Equiva WFE (r	nm lent ms)	Higl	arcsec Allocati h Ord Parar mag (n Hz (-3d	er Sti		0.00	0.00	0.05					0.66	0.79
Total F Science T Tilt Measu. Tilt Anisog Residual C	ligh Order Wa ip/Tilt Errors irement Error (one-axis) olanatism Error (one-exis) elentroid Anisoplanat	ixis) -axis)	Sci Filter	153 n Angula Error (ri 1.96 m 1.24 m 3.26 m 0.55 m	m E E Mass Nass Nass Nass Nass Nass Nass Nass	45 171 Equiva WFE (r)	nm lent ms)	19.0 10.0 42.4	Parar mag (n Hz (-3d arcsec	er Sti		0.00	0.00	0.05					0.66	0.79
Total F Science T Tilt Measu Tilt Bandw Tilt Aniso Residual C Residual A	igh Order Waligh O	ixis) -axis) tism		153 n Angula Error (ri 1.96 m 1.24 m 3.26 m 0.55 m 0.26 m	m Ems) \	45 171 Equiva WFE (ru 33 21 55 9	nm lent ms)	19.0 10.0 42.4 20	Parar mag (m Hz (-3d arcsec x reduc	neter NV) b) from sci		0.00	0.00	0.05					0.66	0.79
Total F Science T Tilt Measu. Tilt Bandw Tilt Aniso; Residual I/ Induced P	ip/Tilt Errors ip/Tilt Errors irement Error (one-axis) olanatism Error (one-axis) olanatism Error (one-axis) standard Anisoplanat timospheric Dispers late Scale Deformati	axis) -axis) tism ion ons	Sci Filter	153 n Angula Error (ri 1.96 m 1.24 m 3.26 m 0.25 m 0.26 m 0.00 m	m Ems) \	45 171 Equiva WFE (r) 33 21 55 9	nm lent ms) nm nm nm nm nm nm nm nm	19.0 10.0 42.4 20 0	mag (n Hz (-3d arcsec x reduc m conj	neter (V) (b) (trom scittion theight		0.00	0.00	0.05					0.66	0.79
Total F Total F Tilt Meast. Tilt Bandw Tilt Anisog Residual A Induced P Non-Com Residual I	ip/Tilt Errors ip/Tilt Errors rement Error (one-axis) planatism Irror (one-axis) p	axis) -axis) tism ion ons	Sci Filter	1.96 m 1.96 m 1.24 m 3.26 m 0.55 m 0.00 m 0.03 m 1.16 m	m E ms) \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \	45 171 Equiva WFE (r) 33 21 55 9 6 0 0	Ient ms) nm	19.0 10.0 42.4 20 20 3.2 mas/	mag (n Hz (-3d arcsec x reduc x reduc m conj	er Str neter (V) (b) (from sci (tion (tion height ion (t distur		0.00	0.00	0.05					0.66	0.79
Total F Total F Tilt Meast. Tilt Bandw Tilt Anisog Residual A Residual A Non-Comm	ip/Tilt Errors ip/Tilt Errors rement Error (one-axis) planatism Irror (one-axis) p	axis) -axis) tism ion ons	Sci Filter	153 n Angula Error (ri 1.96 m 1.24 m 3.26 m 0.55 m 0.26 m 0.00 m 0.03 m	m E ms) \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \	45 171 Equiva WFE (r) 33 21 55 9 6 0 0	nm lent ms) nm	19.0 10.0 42.4 20 20 3.2 mas/	Parar mag (n Hz (-3d arcsec x reduc x reduc	er Str neter (V) (b) (from sci (tion (tion height ion (t distur		0.00	0.00	0.05					0.66	0.79
HO Wavefr Total H Total H Tilt Meass. Tilt Bandw Tilt Anison Residual A Induced P Non-Comi Residual T TT Error M	ip/Tilt Errors ip/Tilt Errors rement Error (one-axis) planatism Irror (one-axis) p	axis) ism ion ons rors tter (one-	Sci Filter H axis)	1.96 m 1.96 m 1.24 m 3.26 m 0.55 m 0.00 m 0.03 m 1.16 m	m E ms) \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \	45 171 Equiva WFE (r) 33 211 55 9 5 0 0 145	Ient ms) nm	19.0 10.0 42.4 20 20 3.2 mass	mag (n Hz (-3d arcsec x reduc x reduc m conj	er Sti neter (V) (b) (from sci tion tion height ion it distur-	bance	0.00			Strei	hl rati	os (%			
HO Wavefr Total H Total H Tilt Meass. Tilt Bandw Tilt Anison Residual A Induced P Non-Comi Residual T TT Error M	ip/Tilt Errors rement Error (one-axis) Janatism Error (one-axis) Janatism Error (one lottroid Anisoplanat throspheric Dispers late Scale Deformati one-Path Tip-Tilt Err elescope Pointing Ji argin	axis) ism ion ons rors tter (one-	Sci Filter H axis)	153 na Angula Error (ri 1.24 m 1.24 m 0.55 m 0.26 m 0.00 m 1.16 m 2.00 m	m E ms) \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \	45 171 Equiva WFE (r) 33 211 55 9 5 0 0 145	nm lent ms) nm	19.0 10.0 42.4 20 20 3.2 mass	mag (n Hz (-3d arcsec x reduc x reduc x reduc th reduce	er Sti neter (V) (b) (from sci tion tion height ion it distur-	bance				Strei	hl rati	os (%			
Total F Tilt Measu Tilt Bandw Tilt Aleasu Tilt Bandw Tilt Alesso Residual C Residual I Induced P Non-Comm Residual T T Error M	igh Order War ip/Titt Errors ip/Titt errors inement Error (one-add)	ixis) -axis) ism ion ons ors tter (one-	Sci Filter H axis)	153 na Angula Error (ri 1.24 m 1.24 m 0.55 m 0.26 m 0.00 m 1.16 m 2.00 m	m E ms) \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \	45 171 Equiva WFE (r) 33 21 555 9 10 20 145	nm lent ms) nm	19.0 10.0 10.0 42.4 20 0 3.2 mas/ 29	arcsec Allocati h Ord Parar mag (n Hz (-3d arcsec x reduu m conj Allocat Hz inpu Allocat	er Sti	bance	0.29	0.42	0.56	Strel	0.72	os (%	0.84	0.90	0.94
Total F Tilt Measu Tilt Bandw Tilt Aleasu Tilt Bandw Tilt Alesso Residual C Residual I Induced P Non-Comm Residual T T Error M	ip/Tilt Errors rement Error (one-axis) Janatism Error (one-axis) Janatism Error (one lottroid Anisoplanat throspheric Dispers late Scale Deformati one-Path Tip-Tilt Err elescope Pointing Ji argin	ixis) -axis) ism ion ons ors tter (one-	Sci Filter H axis)	153 na Angula Error (ri 1.24 m 1.24 m 0.55 m 0.26 m 0.00 m 1.16 m 2.00 m	m E ms) \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \	45 171 Equiva WFE (r) 33 21 555 9 10 20 145	nm lent ms) nm	19.0 10.0 42.4 20 20 3.2 mas/ 29	arcsec Allocati h Ord Parar mag (n Hz (-3d arcsec x reduc x reduc m conj Hz inpt Allocat	er Stri	bance	0.29	0.42	0.56	0.65 0.09	0.72 0.17	0.78 0.27	0.84	0.90	0.94
Total F Tilt Measu Tilt Bandw Tilt Aleasu Tilt Bandw Tilt Alesso Residual C Residual I Induced P Non-Comm Residual T T Error M	igh Order War ip/Titt Errors ip/Titt errors inement Error (one-add)	ixis) -axis) ism ion ons ors tter (one-	Sci Filter H axis)	153 na Angula Error (ri 1.24 m 1.24 m 0.55 m 0.26 m 0.00 m 1.16 m 2.00 m	m E ms) \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \ \	45 171 Equiva WFE (r) 33 21 555 9 10 20 145	nm lent ms) nm	19.0 10.0 42.4 20 20 3.2 mas/ 29	arcsec Allocati h Ord Parar mag (n Hz (-3d arcsec x reduu m conj Allocat Hz inpu Allocat	er Stri	bance	0.29	0.42	0.56	0.65 0.09	0.72 0.17	0.78 0.27	0.84	0.90	0.94
HO Wavefi Total I Total I Tilt Meass Tilt Bandw Tilt Aniso, Residual C Residual I Induced P Non-Comm Residual T T Error M	igh Order War ip/Titt Errors ip/Titt errors inement Error (one-add)	ixis) -axis) ism ion ons ons tter (one-	Sci Filter H axis)	Angula Error (ri 1.96 m 1.24 m 0.25 m 0.03 m 0.03 m 2.00 m	m E E E E E E E E E E E E E E E E E E E	45 171 Equiva WFE (ri 55 9 6 0 0 145 85	nm lent ms) nm	19.0 10.0 10.0 10.0 10.0 10.0 10.0 10.0	arcsec mag (n Hz (-3d arcsec x redux m conj Allocat h Ord Mag (n Hz (-3d arcsec x redux m conj Allocat hz inpu Allocat by/Tilt ttal St	er Stri	bance hl %)	0.29	0.42	0.56	0.65 0.09	0.72 0.17	0.78 0.27	0.84	0.90	0.94
Total F Total F Tilt Measu Tilt Bandw Tilt Alesso Residual C Residual I Induced P Non-Comm Residual T T Error M	igh Order Wagin jp/Tilt Errors rement Error (one-axis) Janatism Error (one-axis) Lip/Tilt Error (ine-axis) Lip/Tilt Error (ine-axis) Lip/Tilt Error (ine-axis)	ixis) -axis) ism ion ons ons tter (one-	Sci Filter H axis)	Angula Error (ri 1.96 m 1.24 m 0.25 m 0.03 m 0.03 m 2.00 m	m E E E E E E E E E E E E E E E E E E E	45 171 Equiva WFE (r) 33 21 555 9 10 20 145	nm lent ms) nm	19.0 10.0 10.0 10.0 10.0 10.0 10.0 10.0	arcsec Allocati h Ord Parar mag (n Hz (-3d arcsec x reduux m conj nAllocat Hz inpu Allocat Hz inpu Hz	er Sti	bance	0.29	0.42	0.56 0.03 12.5	0.65 0.09 14.8	0.72 0.17 17.3	0.78 0.27 20.0	0.84 0.41 24.0	0.90	0.94
HO Wavefi Total F Science T Tilt Meass. Tilt Bandw Tilt Aniso, Residual C Residual C Induced P Non-Comm Residual T TT Error M Total T	igh Order Wagin jp/Tilt Errors rement Error (one-axis) Janatism Error (one-axis) Lip/Tilt Error (ine-axis) Lip/Tilt Error (ine-axis) Lip/Tilt Error (ine-axis)	ixis) -axis) ism ion ons ons tter (one-	Sci Filter H axis)	Angula Error (ri 1.96 m 1.24 m 0.25 m 0.03 m 0.03 m 2.00 m	m E E E E E E E E E E E E E E E E E E E	45 171 Equiva WFE (ri 55 9 6 0 0 145 85	nm lent ms) nm	19.0 19.0 19.0 19.0 19.0 19.0 19.0 19.0	mag (n Hz (-3d) arcsec with the control of the cont	er Sti neter neter neter neter notion tition tition tition Stree (mass	hl %)	0.29 0.00 8.2 50 0.57	0.42 0.00 10.0 70 0.65	0.56 0.03 12.5 90 0.67	0.65 0.09 14.8	0.72 0.17 17.3 240 0.72	0.78 0.27 20.0 400 0.78	0.84 0.41 24.0 800 0.86	0.90	0.94 0.75 41.7
HO Wavefr Total F Science T Tilt Meass. Tilt Bandw Tilt Also, Residual C Residual C Residual T TT Enor M Total T	igh Order Wagin Jip/Tilt Errors Jip/Tilt Errors Jip/Tilt Errors Jip/Tilt Error (one-exis) Janatism Error (one-exis) Janatism Error (one-exis) Janatism Error (one-petrol d'Ansignet) Janatism Error (one-petrol d'Ansignet) Jip/Tilt Error (one-petrol d'Ans	ixis) -axis) ism ion ons ons tter (one-	Sci Filter H axis)	Angula Error (ri 1.96 m 1.24 m 0.05 m 0.00 m 0.03 m 2.00 m	m lar [] as	45 171 171 2quiva 33 21 55 50 0 0 145 85	nm leent ms) nm	19.0 19.0 19.0 19.0 19.0 19.0 19.0 19.0	mag (n Hz (-3d) arcsec with the control of the cont	er Sti neter NV) bb) from sci tion tion tidisturi son Strei (mas 15 0.12	bance hl %) 35 0.43	0.29 0.00 8.2 50 0.57	0.42 0.00 10.0 70 0.65	0.56 0.03 12.5 90 0.67	0.65 0.09 14.8 120 0.68	0.72 0.17 17.3 240 0.72	0.78 0.27 20.0 400 0.78	0.84 0.41 24.0 800 0.86	0.90	0.94 0.75 41.7
HO Wavefr Total F Science T Tilt Meass. Tilt Bandw Tilt Also, Residual C Residual C Residual T TT Enor M Total T	igh Order Wagin Jip/Tilt Errors Jip/Tilt Errors Jip/Tilt Errors Jip/Tilt Error (one-exis) Janatism Error (one-exis) Janatism Error (one-exis) Janatism Error (one-petrol d'Ansignet) Janatism Error (one-petrol d'Ansignet) Jip/Tilt Error (one-petrol d'Ans	ixis) -axis) ism ion ons ons tter (one-	Sci Filter H axis)	Angula Error (ri 1.96 m 1.24 m 0.25 m 0.03 m 0.03 m 2.00 m	m lar [] as	45 171 171 2quiva 33 21 55 50 0 0 145 85	nm lent ms) nm	19.0 19.0 19.0 19.0 19.0 19.0 19.0 19.0	mag (n Hz (-3d) arcsec with the control of the cont	er Sti neter NV) bb) from sci tion tion tidisturi son Strei (mas 15 0.12	bance hl %) 35 0.43	0.29 0.00 8.2 50 0.57	0.42 0.00 10.0 70 0.65	0.56 0.03 12.5 90 0.67	0.65 0.09 14.8 120 0.68	0.72 0.17 17.3 240 0.72	0.78 0.27 20.0 400 0.78	0.84 0.41 24.0 800 0.86	0.90	0.94 0.75 41.7
HO Wasefr Total F Tit Meass Tit Meass Tit Meass Tit Aniso Residual A Induced P Non-Common Total T Total T	igh Order Wagin Jip/Tilt Errors Jip/Tilt Errors Jip/Tilt Errors Jip/Tilt Error (one-exis) Janatism Error (one-exis) Janatism Error (one-exis) Janatism Error (one-petrol d'Ansignet) Janatism Error (one-petrol d'Ansignet) Jip/Tilt Error (one-petrol d'Ans	xis) -axis) ism ion ons ons tter (one- ax The Fro	H Aaxis)	Angula Error (ri 1.96 m 1.24 m 0.05 m 0.00 m 0.03 m 2.00 m	m lar [] as	45 171 171 2quiva 33 21 55 50 0 0 145 85	nm lent ms) nm	19.00 19.00	arcsec Allocati h Ord Parar mag (n Hz (-3d arcsec x reduc x reduc x reduc y reduc y reduc tal St WHM mas) are Lumited	er Sti NV) Normalization strein (mass 15 0.12 0.000	hl %) 35 0.43 0.00	0.29 0.00 8.2 50 0.57	0.42 0.00 10.0 70 0.65 0.02	0.56 0.03 12.5 90 0.67 0.03	0.65 0.09 14.8 120 0.68 0.05	0.72 0.17 17.3 240 0.72 0.18	0.78 0.27 20.0 400 0.78	0.84 0.41 24.0 800 0.86	0.90	0.94 0.75 41.7
HO Wasefr Total F Total F Tilt Meass Tilt Meass Tilt Anisog Residual / Induced P Non-Com Residual I TT Error M Total T	igh Order Wagin Jip/Tilt Errors rement Error (one-axis) Janatism Error (one-axis) Janatism Error (one-british Error (one-british Error (one-axis) Janatism Error (one-british Error	axis) -axis) sism ion ons ors tter (one- ax Cover	H Aaxis)	Angula Error (ri 1.96 m 1.24 m 0.05 m 0.00 m 0.03 m 2.00 m	m lar [] as	455 171 171 33 211 555 60 0 189 189	nm lent ms) nm	19.00 19.00	arcsec Allocati h Ord Parar mag (n Hz (-3d arcsec x reduc x reduc x reduc y reduc y reduc tal St WHM mas) are Lumited	er Sti NV) Normalization strein (mass 15 0.12 0.000	hl %) 35 0.43 0.00	0.29 0.00 8.2 50 0.57 0.01	0.42 0.00 10.0 70 0.65 0.02	0.56 0.03 12.5 90 0.67 0.03	0.65 0.09 14.8 120 0.68 0.05	0.72 0.17 17.3 240 0.72 0.18	0.78 0.27 20.0 400 0.78	0.84 0.41 24.0 800 0.86	0.90	0.94 0.75 41.7
HO Waseff Total F Total F Tilt Meass Tilt Meass Tilt Anisog Residual / Induced P Non-Com Residual I TT Error M Total T	ont Error Margin ligh Order Wa sip/Tilt Errors rement Error (one-axis) Janatism Error (one-axis) Janatism Error (one- entroid Anispheric Dispers Lentroid Anispheric Dispers Lentroid Anispheric Dispers Letter Scale Deformation-Path Tip-Tilt Er elescope Pointing Ji argin Lip/Tilt Error (i	axis) -axis) sism ion ons ors tter (one- ax Cover	H Aaxis)	Angula Error (ri 1.96 m 1.24 m 0.05 m 0.00 m 0.03 m 2.00 m	m lar [] as	455 171 171 33 211 555 60 0 189 189	nm lent ms) nm	19.00 19.00	arcsec Allocati h Ord Parar mag (n Hz (-3d arcsec x reduc x reduc x reduc y reduc y reduc tal St WHM mas) are Lumited	er Sti NV) Normalization strein (mass 15 0.12 0.000	hl %) 35 0.43 0.00	0.29 0.00 8.2 50 0.57 0.01	0.42 0.00 10.0 70 0.65 0.02	0.56 0.03 12.5 90 0.67 0.03	0.65 0.09 14.8 120 0.68 0.05	0.72 0.17 17.3 240 0.72 0.18	0.78 0.27 20.0 400 0.78	0.84 0.41 24.0 800 0.86	0.90	0.94 0.75 41.7
HO Waseff Total H Science T Tilt Meass Tilt Meass Tilt Anison Residual / Induced P Non-Com Residual I TT Error M Total T	igh Order Wasin ip/Tilt Errors rement Error (one-awis) lanatism Error (one-awis) lanatism Error (one-ditting in interest of the interest o	axis) axis) axis) axis) axis) axis) axis) axis axis axis axis axis axis axis axis	H Axis)	Angula Error (rr) 1.96 m 1.24 m 3.26 m 0.05 m 0.00 m 0.03 m 1.16 m 2.00 m 4.7 r Spax	n Ir II	455 1711 1711 1711 1711 1711 1711 1711 1	nm nm lent ms) nm	Higg 19.00 10.0	arcsec Allocation h Ord Parar mag (n Hz (-3d) Allocation m conj Allocat Hz inpl Allocat WHM whith mas) are Limited	er Sti neter NV) b) b) b) construction tition tition tition Strel (mas 15 0.12 0.00	hl %) 35 0.43 0.00	0.29 0.00 8.2 50 0.57 0.01	0.42 0.00 10.0 70 0.65 0.02	0.56 0.03 12.5 90 0.67 0.03	0.65 0.09 14.8 0.05	0.72 0.17 17.3 240 0.72 0.18	0.78 0.27 20.0 400 0.78 0.42	0.84 0.41 24.0 800 0.86 0.88	0.90	0.94 0.75 41.7 36 0.50
HO Waseff Total H Science T Tilt Meass Tilt Meass Tilt Anison Residual / Induced P Non-Com Residual I TT Error M Total T	ont Error Margin ligh Order Wa ligh Order Wa lip/Tilt Errors rement Error (one- did the fror (one- did the f	axis) axis) axis) axis) sism sion sons ors tter (one- Cover	H H axis)	Angula Error (rr) 1.96 m 1.24 m 3.26 m 0.05 m 0.00 m 0.03 m 1.16 m 2.00 m 4.7 r Spax	n I I I I I I I I I I I I I I I I I I I	45 171 171 171 171 171 171 171 171 171 17	nm nm lent ms) nm	Higg 19.00 10.0	arcsec Allocation h Ord Parar mag (n Hz (-3d arcsec x reduu m conj Allocat Hz ind Hz	er Sti neter N) bb) bcom sci tition height ion st disturion Strei (mas 15 0.12 0.00	hl %) 35 0.43 0.00	0.29 0.00 8.2 50 0.57 0.01	0.42 0.00 10.0 70 0.65 0.02	0.56 0.03 12.5 90 0.67 0.03	0.65 0.09 14.8 0.05	0.72 0.17 17.3 240 0.72 0.18	0.78 0.27 20.0 400 0.78 0.42	0.84 0.41 24.0 800 0.86 0.88	0.90	0.94 0.75 41.7 36 0.50
HO Waseff Total H Science T Tilt Meass Tilt Meass Tilt Anison Residual / Induced P Non-Com Residual I TT Error M Total T	igh Order Wasin ip/Tilt Errors rement Error (one-awis) lanatism Error (one-awis) lanatism Error (one-ditting in interest of the interest o	axis) axis) axis) axis) isim ion ons ons ons tter (one- Cover- Cover- 30 0.147	H H axis)	Angula Error (rr) 1.96 m 1.24 m 3.26 m 0.05 m 0.00 m 0.03 m 1.16 m 2.00 m 4.7 r Spax	n ir i i i i i i i i i i i i i i i i i i	455 1711 1711 1711 1711 1711 1711 1711 1	nm lent ms) nm	Higg 19.00 10.0	arcsec Allocation Allocation Mag (n Mz (-3d) Allocation M conj Allocat M conj M co	er Sti neter NV) bb) from soci tition telight ion t disturion Strel (mas 15 0.12 0.000	hl %) 35 0.43 0.00	0.29 0.00 8.2 50 0.57 0.01	0.42 0.00 10.0 70 0.65 0.02	0.56 0.03 12.5 90 0.67 0.03	0.65 0.09 14.8 0.05	0.72 0.17 17.3 240 0.72 0.18	0.78 0.27 20.0 400 0.78 0.42	0.84 0.41 24.0 800 0.86 0.88	0.90	0.94 0.75 41.7 36 0.50
HO Wasefi Total F Science T Tilt Meass Tilt Meass Tilt Anison Residual / Induced P Non-Com Residual I TT Error M Total T Total Effect Ensquare Corres Sky Cover	igh Order Wargin ligh Order Wargin ligh Order Wargin lip/Tilt Errors rement Error (one-axis) lanatism Error (one-dith Error (one-axis) lanatism Error (one lanatism Error (one-dith Error (one-axis) lanatism Error (one-axis) lanatism Error (one-axis) lanatism Error (one-axis) lip/Tilt Error (one-axis) descript Pointing Ji argin lip/Tilt Error (one-axis) descript Pointing Ji argin descript Pointing Para Zenith Angle of the table Ji wind Speed	Cover	H H axis) r deg m arasec m/s	Angula Error (rr) 1.96 m 1.24 m 3.26 m 0.05 m 0.00 m 0.03 m 1.16 m 2.00 m 4.7 r Spax	n Fire Factor Parameter Pa	45 1711 33 218 555 556 556 60 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	nm lent ms) nm nm nm nm nm nm nm nm nm n	High	arcsec Allocation of statement	er Sti neter n	bance %) 35 0.43 0.00	0.29 0.00 8.2 50 0.57 0.01	0.42 0.00 10.0 70 0.65 0.02 Total Et	0.56 0.03 12.5 90 0.67 0.03	0.65 0.09 14.8 120 0.68 0.05	0.72 0.17 17.3 240 0.72 0.18	0.78 0.27 20.0 400 0.78 0.42	0.84 0.41 24.0 800 0.86 0.88	0.90	0.94 0.75 41.7 366 0.50
HO Waseff Total H Science T Tilt Meass Tilt Meass Tilt Anison Residual / Induced P Non-Com Residual I TT Error M Total T	igh Order Wargin ligh Order Wargin ligh Order Wargin lip/Tilt Errors rement Error (one-awa) Janatism	covers Covers	H H age deg m mrssec m/s m	Angula Error (rr) 1.96 m 1.24 m 3.26 m 0.05 m 0.05 m 0.06 m 1.16 m 2.00 m 4.7 r Spax	n	45 171 171 171 171 171 171 171 171 171 17	nm lent ms) nm nm nm nm nm nm nm nm nm n	High	arcsec Allocation of site of the control of site of site of the control of site	er Sti neter N) bb) brom sol tion height ion t disturion t disturion t disturion t mass 15 0.12 0.00 y can b arcmin W	hl %) 35 0.43 0.00	0.29 0.00 8.2 50 0.57 0.01	0.42 0.00 10.0 70 0.65 0.02 Total Et	0.56 0.03 12.5 90 0.67 0.03	0.65 0.09 14.8 0.05	0.72 0.17 17.3 240 0.72 0.18	0.78 0.27 20.0 400 0.78 0.42	0.84 0.41 24.0 800 0.86 0.88	0.90	0.94 0.75 41.7 366 0.50
HO Wasefi Total F Total F Tilt Meass Tilt Meass Tilt Bandwin Tilt Anison Residual / Induced P Non-Com Residual I TT Error M Total T Total T Total Effect Ensquare Corres Sky Cover	igh Order Wargin ligh Order Wargin ligh Order Wargin lip/Tilt Errors rement Error (one-aki) Janatism	covers Covers	H H axis) r deg m arasec m/s	Angula Error (rr) 1.96 m 1.24 m 3.26 m 0.05 m 0.05 m 0.06 m 1.16 m 2.00 m 4.7 r Spax	n	45 1711 33 321 55 60 60 60 85 45 45 45 46 46 47 47 47 47 47 47 47 47 47 47 47 47 47	nm lent ms) nm	Higg 19.0	mag (n Hz (-3d arcsec Allocati h Ord Mag (n Hz (-3d arcsec Allocati Mag (n Hz (-3d arcsec Allocat All	er Sti neter neter noter n	bance %) 35 0.43 0.00	0.29 0.00 8.2 50 0.57 0.01	0.42 0.00 10.0 70 0.65 0.02 Total Et	0.56 0.03 12.5 90 0.67 0.03	0.65 0.09 14.8 120 0.68 0.05	0.72 0.17 17.3 240 0.72 0.18	0.78 0.27 20.0 400 0.78 0.42	0.84 0.41 24.0 800 0.86 0.88	0.90	0.94 0.75 41.7 366 0.50
HO Wasefi Total F Science T Tilt Meast Tilt Bandwin Tilt Anison Residual / Induced P Non-Com Residual I TT Error M Total T Total Effect Ensquare Corres Assumptic	igh Order Wagin ligh Order Wagin ligh Order Wagin p/Tilt Errors rement Error (one-axis) Janatism Error (one-dith Error (one-axis) Janatism Error (one fentroid Anisoplanat tmospheric Dispers throughperic Dispers ip/Tilt Error (relates one fentroid Anisoplanat tmospheric Dispers ip/Tilt Error (relates one fentroid Anisoplanat tmospheric Dispers ip/Tilt Error (relates one fentroid Anisoplanat through Tilt Error (relates one fentroid Anisoplanat through Tilt Error (relates one fentroid Anisoplanat age ponding Sky ponding Sky ins / Parameter in / Observing Para Zenith Anisoplanat through Tilt Anisoplanat through Tilt Error (relates one fentroid Anisoplanat	cover Cover Cover Cover 10.97 10.97 10.97 10.97 10.97 10.97 10.97 10.97 10.97 10.97 10.97 10.97 10.97 10.97 10.97	H H age deg m mrssec m/s m	Angula Error (rr) 1.96 m 1.24 m 3.26 m 0.05 m 0.05 m 0.06 m 1.16 m 2.00 m 4.7 r Spax	n	45 1711 333 215 55 60 00 145 189 189 60 30% 85 8 Asteriariantetess 8 Asteriariantetess 8 Asteriariantetess 9 WFS Notice WFS WFS Notice 85 85 86 87 87 87 88 87 88 88 88 88 88 88 88 88	nm lent ms) nm	Higg 19.0	arcsec Allocation of State of	er Sti neter Ny) bb) bb) to to make it disturition height ion Strel (mas 15 0.02 0.00 arcmin W using e-ms	bance hl %) 35 0.43 0.00 cCCID74	0.29 0.00 8.2 50 0.57 0.01	0.42 0.00 10.0 70 0.65 0.02 Total Et	0.56 0.03 12.5 90 0.67 0.03	0.65 0.09 14.8 120 0.68 0.05	0.72 0.72 17.3 240 0.72 0.18	0.78 0.27 20.0 400 0.78 0.42	0.84 0.41 24.0 800 0.86 0.88	0.90	0.94 0.75 41.7 36 0.50
HO Wasefi Total F Science T Tilt Meast Tilt Bandwin Tilt Anison Residual / Induced P Non-Com Residual I TT Error M Total T Total Effect Ensquare Corres Assumptic	ing Fror Margin ligh Order Wa ligh Order Wa lip/Tilt Errors rement Error (one-aki) lanatism Err	axis) axis) axis) axis) sism son ons ons ons ons ons ons ons ons ons	H H axis) r H deg m arcsec m/s m/s x 109 cm	Angula Error (rr) 1.96 m 1.24 m 3.26 m 0.05 m 0.05 m 0.06 m 1.16 m 2.00 m 4.7 r Spax	n	45 1711 33 35 56 60 60 220 28 85 189 189 189 189 189 189 189 189 189 189	nm lent ms) nm	Higg 19.0	arcsec Allocation of State of	er Sti neter neter NV) b) to foom solition feight ion food Strei (mas 15 0.12 0.00 y can b arcmin W using e-rms	bance hl %) 35 0.43 0.00 cCCID74	0.29 0.00 8.2 50 0.57 0.01	0.42 0.00 10.0 70 0.65 0.02 Total Et	0.56 0.03 12.5 90 0.67 0.03	0.65 0.09 14.8 120 0.68 0.05	0.72 0.72 17.3 240 0.72 0.18	0.78 0.27 20.0 400 0.78 0.42	0.84 0.41 24.0 800 0.86 0.88	0.90	0.94 0.75 41.7 36 0.50
HO Wasefi Total F Science T Tilt Meass Tilt Meass Tilt Anison Residual / Induced P Non-Com Residual I TT Error M Total T Total Effect Corres Assumptic Atmosphe	int Error Margin ligh Order Wa ligh Order Wa lip/Tilt Errors rement Error (one-add) rement Error (one-add) lanatism Error	wis) axis) axis) axis) ism ion ons tter (one-ax tter (one-ax 1.077 50 3 MOAO Indep Pn	H H axis) r H deg m arcsec m/s m/s x 109 cm	Angula Error (rr) 1.96 m 1.24 m 3.26 m 0.05 m 0.05 m 0.20 m 1.16 m 2.00 m 4.7 r Spax	n I I I I I I I I I I I I I I I I I I I	455 1771 33 212 555 9 9 10 1771 1785 189 189 189 189 189 189 189 189 189 189	Inm Ilent Inm	Higg 19.00 19.0	arcsec Allocation of State Sta	er Sti neter neter his bi bi bi bi bi con streen frehl (frehl (bance hl %) 35 0.43 0.00 cCCID74	0.29 0.00 8.2 50 0.57 0.01	0.42 0.00 10.0 70 0.65 0.02 Total Et	0.56 0.03 12.5 90 0.67 0.03	0.65 0.09 14.8 120 0.68 0.05	0.72 0.72 17.3 240 0.72 0.18	0.78 0.27 20.0 400 0.78 0.42	0.84 0.41 24.0 800 0.86 0.88	0.90	0.94 0.75 41.7
HO Wasefi Total F Total F Tilt Meass Tilt Meass Tilt Bandwin Tilt Anison Residual / Induced P Non-Com Residual I TT Error M Total T Total T Total Effect Corres Sky Cover Corres Atmosphe	igh Order Wargin ligh Order Wargin ligh Order Wargin ligh Order Wargin ligh Order Wargin light Error (one-axis) lanatism Error (light State of the Indian India	Covers Covers	H Auxis) Is) H age deg m arcsec m/s m x 109 cm	Angula Error (rr) 1.96 m 1.24 m 3.26 m 0.05 m 0.05 m 0.20 m 1.16 m 2.00 m 4.7 r Spax	n I I I I I I I I I I I I I I I I I I I	455 1711 33 212 555 9 9 5 6 0 0 22 22 145 85 85 85 85 85 87 87 88 87 88 88 88 88 88 88 88 88 88	Inm Ilent Inm	Higg 19.00 19.0	arcsec Allocation of Allocation of Signature	er Sti neter neter his bi bi bi bi bi con streen frehl (frehl (bance hl %) 35 0.43 0.00 cCCID74	0.29 0.00 8.2 50 0.57 0.01	0.42 0.00 10.0 70 0.65 0.02 Total Et	0.56 0.03 12.5 90 0.67 0.03	0.65 0.09 14.8 120 0.68 0.05	0.72 0.72 17.3 240 0.72 0.18	0.78 0.27 20.0 400 0.78 0.42	0.84 0.41 24.0 800 0.86 0.88	0.90	0.94 0.75 41.7 36 0.50
HO Wasefi Total F Total F Tilt Measur Tilt Bandw Tilt Anison Residual / Induced P Non-Com Residual I TT Error M Total T Total T Total T Cotal Effect Atmosphe AO Modes	int Error Margin ligh Order Wa ligh Order Wa lip/Tilt Errors rement Error (one-add) rement Error (one-add) lanatism Error	wis) axis) axis) axis) ism ion ons tter (one-ax tter (one-ax 1.077 50 3 MOAO Indep Pn	H Askis) IS) H deg mm arcsec m/s x 109 cm	Angula Error (rr) 1.96 m 1.24 m 3.26 m 0.05 m 0.05 m 0.06 m 1.16 m 2.00 m 4.7 r Spax	n	455 1771 33 212 555 9 9 10 1771 1785 189 189 189 189 189 189 189 189 189 189	nm lent ms) Ident ms) Inm nm n	Higg 19.00 19.0	arcsec Allocation of State Sta	er Sti neter neter his bi bi bi bi bi con streen frehl (frehl (bance hl %) 35 0.43 0.00 cCCID74	0.29 0.00 8.2 50 0.57 0.01	0.42 0.00 10.0 70 0.65 0.02 Total Et	0.56 0.03 12.5 90 0.67 0.03	0.65 0.09 14.8 120 0.68 0.05	0.72 0.72 17.3 240 0.72 0.18	0.78 0.27 20.0 400 0.78 0.42	0.84 0.41 24.0 800 0.86 0.88	0.90	0.94 0.75 41.7 36 0.50

Transients



Resolved Stellar Populations

	ons/sky cov		choot"	I allow	toors	niza chu	rago L.	chanci-	n2	ter										
Purpose:		in order to	o balance	the error b	udget te	nize sky cove erms; several	of the I	nput Sun	nmary ce	lls poin										
		How exac	tly to opt	imize depe	nds on v	vhether the s	cience	case is No	SS, LGS	n-axis,	or LGS f	ield stars	(sky co	verage)						
Solver Inpu	it Values	NGS	LGS			Current Sett	ings													
HO guide st	ar brightness	LGS		mV		48	PDF/si	ubap/exp			Ontimiza	e LGS Of	-Pointing	12	N					
Optim HO in	tegration time:	0.00050	0.0010	sec		1020		аварі скр			Optimiz	e LGS Ra	nge Gat	e?	N					
	erture width: ar brightness	0.174 LGS	0.174	meters mV			Subaps	S			Optimiz	e Subap	Diamete	er?	N	0.182	m	Non-optii	m subap	width
TT integratio	n time	0.00050	0.0044			226														
TT guide sta	r distance star birghtness	LGS	46.3 18.7	arcsec																
TWFS integr	ration time	0.0	6.2993	sec		0.16	Hz													
TWFS guide	star search radius ser beacons	0.0	46.3	arcsec			_	_	_			_								
LGS asterisr		0.0		arcmin		Set ast rad =	0.001 fc	or single L	.GS		Optimiz	e LGS ast	terism ra	adius?	N	< not	yet imple	mented (11/18/08)
Ceck Way	efront Error	Buda	et Sur	nmarv		Version 2.1									Scie	ence l	Band			
lode:	NGAO LGS											u'	g'	ď	i'	Z		J	Н	K
	DAVINCI										λ (μμ)		0.47 0.14	0.62	0.75 0.15	0.88	1.03 0.12	1.25 0.16	1.64 0.29	0.3
i. Observation	Resolved Stellar F	opulation	s								δλ (μμ) Δ (μασ)	6.7	8.8	11.6	14.1	16.6	19.4	23.5	30.8	
cience Hiç	gh-order Erro	ors (LG	S Mod	le)		Wavefr Error (r			Parar	neter					Stre	hl Rat	io (%)			
Atmospheri Bandwidth	ic Fitting Error Error						nm nm		Subaps Hz (-3d											
High-order	Measurement Erro	r				80	nm	50	W											
LGS Tomogr	aphy Error formation Error						nm	0.50	sci bea m LLT	con(s)										
Chromatic E	rror					2	nm		Upper li	mit										
Dispersion I	Displacement Erro					29	nm		Estimat	e										
Multispectr Scintillation			ľ				nm		zen; sc Scint in		.5um									
WFS Scintill							nm		Allocati											
Uprorrectal	ole Static Telescope	Aberratio	ons	154	nm	,40	nm	64	Acts Ac	ross P	ıpil									
Uncorrectat	ole Dynamic Telesc	ope Aberra				34	nm		Dekens	Ph.D										
	Zero-point Calibrat		ır				nm	-	Allocati											
Leaky Integ	FS Zero-point Calib rator Zero-point Ca	libration E	rror			10	nm		Allocati	on										
Stale Recon Go-to Contr	structor Error						nm		Allocati											
	oi Errors Layer Focus Chang	ęe					nm	30	m/s Na		ı									
DM Finite S	troke Errors					5	nm		um P-P											
DM Hystere High-Order	sis Aliasing Error						nm		from TM Subaps											
DM Drive Di	igitization					1	nm		bits											
	ole AO System Abe						nm		Allocati											
DM-to-lens	let Misregistration					15	nm		Allocati	on										
DM-to-lens	let Pupil Scale Erro	r			nm	15	nm		Allocati	on										
Angular Ani	soplanatism Error			107	nm	94	nm	5.0	arcsec											
	nt Error Margin					45	nm		Allocati	on										
Total Hi	gh Order Wa	vefront	t Error	188	nm	215	nm	Hial	n Ord	er Str	rehl	0.00	0.00	0.01	0.04	0.10	0.18	0.31	0.51	0.6
	g o																			
cience Tip	/Tilt Errors			Angu Error (Equiva WFE (r		1	Parar	neter					Strei	ni ratio	os (%))		
			Sci Filter																	
	ement Error (one-a th Error (one-axis)	ixis)			mas mas		nm		mag (m Hz (-3d											
	anatism Error (one	-axis)		4.13	mas	65	nm	46.3	arcsec	rom sci										
	ntroid Anisoplanat mospheric Dispers		ľ		mas mas		nm		x reduc											
Induced Pla	ite Scale Deformati	ons		0.00	mas	C	nm	0	m conj	height										
Non-Comm	on-Path Tip-Tilt En	rors	nvis)		mas		nm	3.2 mas/			bance									
Residual Te TT Error Mar	lescope Pointing Ji rgin	iter (one-a	axis)		mas mas		nm	29	Hz inpu Allocat		uance									
													0.00		0.11	0	0.55	0 ===	0.55	0.1
																0.58	0.65	0.73	0.82	0.8
Total Ti	p/Tilt Error (one-axi	s)	6.4	mas	100	nm	Ti	p/Tilt	Strel	nl	0.18	0.20	0.40	0.43					
				6.4	mas												0.40	0.00	0.40	0.0
	p/Tilt Error (6.4	mas		nm		p/Tilt tal St						0.02		0.12	0.23	0.42	0.62
				6.4	mas			То		rehl (%)		0.00	0.00		0.06				
						236	nm	To	tal St WHM	rehl (%)	9.3	0.00	0.00	0.02	0.06	20.5	24.4		41.9
	tive Wavefron						nm	To	tal St WHM mas)	rehl (%)	0.00	0.00	0.00	0.02 15.5	0.06	20.5			
otal Effect	tive Wavefron		r			236	nm	To F	tal St WHM mas)	rehl (' (mas	%) 35	9.3 50 0.05	0.00 10.9 70 0.06	0.00 13.3 90 0.07	0.02 15.5	0.06 17.8 240 0.19	20.5 400 0.35	24.4 800 0.66		41.9
otal Effect	tive Wavefron		r	Spa	axel/	236 Aperture	nm	To F neter (tal St WHM mas)	rehl ('mas	%) 35 0.04	9.3 50 0.05	0.00 10.9 70 0.06	0.00 13.3 90 0.07	0.02 15.5 120 0.08	0.06 17.8 240 0.19	20.5 400 0.35	24.4 800 0.66		41.
otal Effect	tive Wavefron		r		axel/	236 Aperture	nm	To F neter (tal St WHM mas)	rehl ('mas	%) 35 0.04	9.3 50 0.05	0.00 10.9 70 0.06	0.00 13.3 90 0.07	0.02 15.5 120 0.08	0.06 17.8 240 0.19	20.5 400 0.35	24.4 800 0.66		41.
otal Effect nsquared ky Covera	tive Wavefron	nt Error	ľ	Spa	axel/	236 Aperture	nm	Foneter (WHM mas)	15 0.03 0.00	%) 35 0.04 0.00	9.3 50 0.05	0.00 10.9 70 0.06 0.01	0.00 13.3 90 0.07 0.02	0.02 15.5 120 0.08 0.04	0.06 17.8 240 0.19 0.13	20.5 400 0.35	24.4 800 0.66		41.
otal Effect nsquared ky Covera	Energy uge	nt Erron	ľ	Spa	axel/	236 Aperture	nm	Foneter (WHM mas)	15 0.03 0.00	%) 35 0.04 0.00	9.3 50 0.05 0.01	0.00 10.9 70 0.06 0.01	0.00 13.3 90 0.07 0.02	0.02 15.5 120 0.08 0.04	0.06 17.8 240 0.19 0.13	20.5 400 0.35	24.4 800 0.66		41.
otal Effect insquared iky Covera	Energy	nt Erron	ľ	Spa	axel/	236 Aperture	nm	Foneter (WHM mas)	15 0.03 0.00	%) 35 0.04 0.00	9.3 50 0.05 0.01	0.00 10.9 70 0.06 0.01	0.00 13.3 90 0.07 0.02	0.02 15.5 120 0.08 0.04	0.06 17.8 240 0.19 0.13	20.5 400 0.35	24.4 800 0.66		41.
nsquared ky Covera Corresp ssumption	Energy ge ponding Sky ms / Paramete	Covera	ı' age	Spa	axel /	236 Aperture 60 30%	nm Dian	Foneter (Squ Seeing-	whm mas) are Limited	15 0.03 0.00 y can be	%) 35 0.04 0.00	9.3 50 0.05 0.01	0.00 10.9 70 0.06 0.01	0.00 13.3 90 0.07 0.02	0.02 15.5 120 0.08 0.04	0.06 17.8 240 0.19 0.13	20.5 400 0.35 0.33	24.4 800 0.66 0.78	31.5	41.5 560 0.50
nsquared ky Covera Correspondent Sumption	Energy lige conding Sky	Covera	r I'	Spa	axel /	Aperture	nm Dian	Foneter (Squ Seeing-	whm mas) are Limited	(mas 15 0.03 0.00 y can b	%) 35 0.04 0.00	9.3 50 0.05 0.01	0.00 10.9 70 0.06 0.01 Total Eff	0.00 13.3 90 0.07 0.02 fective W	0.02 15.5 120 0.08 0.04	0.06 17.8 240 0.19 0.13	20.5 400 0.35	24.4 800 0.66	31.5	41.5 560 0.50
nsquared ky Coveras Corresp ssumption	Energy age conding Sky ms / Paramete ic/ Observing Para Zenith Angle ro	Covera Ers O 0.123 1.331	r r age	Spa	axel /	236 Aperture 60 30% Parameters LGS Apenier BTO Transmi	nm Dian Dian Radius	For squeeze Seeing-	tal St WHM mas) are Limited 0.17 50 0.60	(mas 15 0.03 0.00 y can b	%) 35 0.04 0.00	9.3 50 0.05 0.01 led to the	0.00 10.9 70 0.06 0.01 Total Eff	0.00 13.3 90 0.07 0.02	0.02 15.5 120 0.08 0.04	0.06 17.8 240 0.19 0.13	20.5 400 0.35 0.33	24.4 800 0.66 0.78	31.5	41.5 560 0.50
nsquared ky Covera Corresponders Atmospheri	Energy Ige Conding Sky Ins / Paramete Left / Observing Para Zentth Angle of thead, ef wind Speed	Covera ers 50 0.123 1.331 14.78	l' age deg m arcsec m/s	Spa	axel /	Aperture 60 30% Parameters LGS Asterisr LGS Power BTO Transmit HO WFS Tra	nm Dian deg	For squeeze Seeing-	wHM mas) mase Limited 0.17 50 0.60 0.37	15 0.03 0.00 y can be	35 0.04 0.00	0.00 9.3 50 0.05 0.01 led to the	0.00 10.9 70 0.06 0.01 Total Eff 18.9 Values	0.00 13.3 90 0.07 0.02 ective W	0.02 15.5 120 0.08 0.04	0.06 17.8 240 0.19 0.13	20.5 400 0.35 0.33	24.4 800 0.66 0.78	31.5	41. 560 0.50
nsquared ky Covera Correspondent Atmospheri	Energy age conding Sky ms / Paramete ic/ Observing Para Zenith Angle ro	Covera Covera 1.331 14.78	l' age deg m arcsec m/s	Spa Galactic La	axel /	Aperture 60 30% Parameters LGS Asterisr LGS Power BTO Transh HO WFS To; HO WFS To; HO WFS No;	nm Dian deg n Radius	Fineter (Squ Seeing-	WHM white wh	15 0.03 0.00 y can be	%) 35 0.04 0.00	0.00 9.3 50 0.05 0.01 led to the	0.00 10.9 70 0.06 0.01 Total Eff 18.9 Values	0.00 13.3 90 0.07 0.02 ective W	0.02 15.5 120 0.08 0.04	0.06 17.8 240 0.19 0.13	20.5 400 0.35 0.33	24.4 800 0.66 0.78	31.5	41. 560 0.50
otal Effect nsquared ky Covera Corresp ssumption	Energy Bige Conding Sky Bige Conding Sky Bige Conding Sky Bige Conding Sky Bige	Covera Covera 1.331 14.78	deg m arcsec m/s m	Spa Galactic La	axel /	Aperture 60 30% Parameters LGS Asterisr LGS Asterisr HO WFS Tyr HO WFS Tyr HO WFS No:	nm Dian deg n Radius nsmission ssion see i-aliasin	To F Squ Seeing- This fract	www.mas) mas) are Limited 0.17 50 0.60 0.37 SH 1.8 NO	15 0.03 0.00 y can be arcmin W	35 0.04 0.00	9.3 50 0.05 0.01 LOWFS 19.7	0.00 10.9 70 0.06 0.01 Total Eff 18.9 Values HO WFS	0.00 13.3 90 0.07 0.02 fective W	0.02 15.5 120 0.08 0.04	0.06 17.8 240 0.19 0.13	20.5 400 0.35 0.33	24.4 800 0.66 0.78	31.5	41. 560 0.50
otal Effect insquared Corresponding Atmospheri	Energy Ige conding Sky ns / Parametr ic/ Observing	Covera Ers 50 0.123 1.331 1.478 3	deg m arcsec m/s m	Spa Galactic La	axel /	Aperture 60 30% Parameters LGS Asteriar LGS Power BTO Transmit HO WFS Trg HO WFS NO: HO WFS NO: HO WFS NO: LO WFS Ant	nm Dian deg n Radius ssion nsmission see i-aliasin smissios	To F Squ Seeing- This fract	wHM mas) are Limited 0.17 50 0.037 SH 1.88 NO 0.28	15 0.03 0.00 y can be	%) 35 0.04 0.00	9.3 50 0.05 0.01 LO WFS 19.7	0.00 10.9 70 0.06 0.01 Total Eff Magnitus 18.9 Values HO WFS	0.00 13.3 90 0.07 0.02 dective W	0.02 15.5 120 0.08 0.04	0.06 17.8 240 0.19 0.13 16.8 1020 48	20.5 400 0.35 0.33	24.4 800 0.66 0.78	31.5	41. 560 0.50
insquared Corresponding Atmospheric Adolesce	Energy Bige Conding Sky Bige Conding Sky Bige Conding Sky Bige Conding Sky Bige	Covera Covera Brs 50 0.123 1.331 14.78 50 3	deg m arcsec m/s m/s x 100 cm-	Spa Galactic La	axel /	Aperture 60 30% Parameters LGS Asterism LGS Power BTO Transmit HO WFS Tra HO WFS Try HO WFS Noi- HO WFS Tra LO WFS Tran LO WFS Tran LO WFS Tran LO WFS Tran	nm Dian deg deg n Radius nsisinissionista suota	To F Squ Seeing- This fract	0.17 50 0.66 0.37 SH NO 0.288 SH 3.2	15 0.03 0.00 y can be arcmin W	%) 35 0.04 0.00	9.3 50 0.05 0.01 LO WFS 19.7	0.00 10.9 70 0.06 0.01 Total Eff Magnitus 18.9 Values HO WFS	0.00 13.3 90 0.07 0.02 dective W	0.02 15.5 120 0.08 0.04	0.06 17.8 240 0.19 0.13 16.8 1020 48	20.5 400 0.35 0.33	24.4 800 0.66 0.78	31.5	41. 560 0.50
insquared Corresponding Sample of Atmosphere	Energy Inge Conding Sky Sky Conding Sky	Covers meters 50 1.331 14.78 50 3 MOAO	deg m arcsec m/s m/s x 100 cm-	Spa Galactic La	axel /	Aperture 30% Parameters LGS Asteriar LGS Asteriar LGS Power BTO Transmi HO WFS Typ HO WFS Noll HO WFS And LO WFS Tran LO WFS	nm deg deg n Radius ssion nsmission ee ei-i-aliasin smissio	To F F Seeing- This fract	0.17 50 0.60 0.37 SH 1.88 NO 0.28 SH	15 0.03 0.00 y can be arcmin W using e-rms	%) 35 0.04 0.00	9.3 50 0.05 0.01 LO WFS 19.7	0.00 10.9 70 0.06 0.01 Total Eff Magnitus 18.9 Values HO WFS	0.00 13.3 90 0.07 0.02 dective W	0.02 15.5 120 0.08 0.04	0.06 17.8 240 0.19 0.13 16.8 1020 48	20.5 400 0.35 0.33	24.4 800 0.66 0.78	31.5	41.5 560 0.50
insquared Corresponding Atmospheric	Energy Inge Conding Sky Inge Conding Sky Inge Conding Sky Inge Conding Sky Inge	Coveras Cov	deg m arcsec m/s m/s x 100 cm-	Spa Galactic La	axel /	Aperture 60 30% Parameters LGS Asterior LGS Power BTO Transmit HO WFS Typ HO WFS Tool HO WFS Tool HO WFS Tool HO WFS Tool HO WFS Ant LO WFS Tand LO WFS Tand To WFS Type To	nm Dian deg deg n Radius ssion nsmissio ei-i-aliasin ssmissio e Type: ttion Ba	To F F Seeing- This fract	0.17 50 0.66 0.37 SH NO 0.288 SH 3.2	15 0.03 0.00 y can be arcmin W using e-rms	%) 35 0.04 0.00	9.3 50 0.05 0.01 LO WFS 19.7	0.00 10.9 70 0.06 0.01 Total Eff Magnitus 18.9 Values HO WFS	0.00 13.3 90 0.07 0.02 dective W	0.02 15.5 120 0.08 0.04	0.06 17.8 240 0.19 0.13 16.8 1020 48	20.5 400 0.35 0.33	24.4 800 0.66 0.78	31.5	41.9
Correspondent Atmospheric Atmo	Energy Ige conding Sky ns / Parametr ic / Observing Para Zenith Angle of Operation Godure Scale Outer Scale Outer Scale Outer Scale Outer Scale Wife's for IT meass, with Speed Outer Scale Wife's for IT meass,	COvera Covera S0 0.123 1.331 14.78 50 0 indep PnS	deg m arcsec m/s m/s x 100 cm-	Spa Galactic La	axel /	Aperture 30% Parameters LGS Asteriar LGS Asteriar LGS Power BTO Transmi HO WFS Typ HO WFS Noll HO WFS And LO WFS Tran LO WFS	nm Dian deg n Radius sssion nsmission see see eType: ttion Ba	To F F Seeing- This fract	0.17 50 0.60 0.37 SH 1.88 NO 0.28 SH	rehl ((mas 15 0.03 0.00 y can be arcmin W using e- rms Hz	%) 35 0.04 0.00	9.3 50 0.05 0.01 LO WFS 19.7	0.00 10.9 70 0.06 0.01 Total Eff Magnitus 18.9 Values HO WFS	0.00 13.3 90 0.07 0.02 dective W	0.02 15.5 120 0.08 0.04	0.06 17.8 240 0.19 0.13 16.8 1020 48	20.5 400 0.35 0.33	24.4 800 0.66 0.78	31.5	41.5 560 0.50

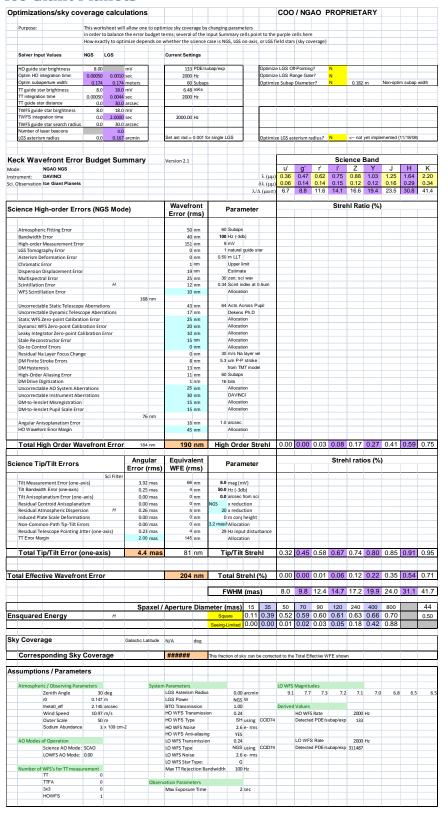
Debris Disks and YSOs

-	ions/sky co											-	,		PROPI					
Purpose:		This wor	ksheet wi to balance	II allow one to the error bu	o optimi idget ten	ze sky cove ms; several	rage by of the I	changing participated in changing participated participated in changing participated in changing participated participated in changing participated in changing participated partic	aramete ary cell	ers s poin	t to the	purple o	ells here							
				timize depen																
Solver Inp	out Values	NGS	LGS		c	urrent Sett	ngs		_											
								ubap/exp			O-M-1-	100.04	Deletie							
	star brightness integration time:	UGS 0.00050	0.0010	mV sec		1020		ubap/exp				e LGS Off e LGS Ra			N					
	aperture width:	0.174 LGS		meters mV		60 11.10	Subap:	s	4		Optimiz	e Subap	Diamete	er?	N	0.182	m	Non-opti	m subap	width
TT integrati	tar brightness ion time	0.00050				226														
TT guide st	tar distance	0.0	60.0	arcsec					_											
	le star birghtness gration time	LGS 0.0		mV sec		0.50	Hz													
TWFS guid	le star search radius laser beacons	0.0	60.0	arcsec .					_	_										
LGS asteris		0.0		arcmin	s	et ast rad =	0.001 fc	or single LG	3		Optimiz	e LGS ast	erism ra	dius?	N	< not	yet imple	mented (11/18/08)
Cook Was	vefront Erro	Dude	ot Cu	mmanı		ersion 2.1				-					Scie	ence l	Rand			
Node:	NGAO LGS	Duuç	jet ou	illillai y	V	ersion 2.1						u'	g'	ď	i'	Z	Y	J	Н	K
strument:	DAVINCI										λ (μμ)	0.36	0.47	0.62	0.75	0.88	1.03	1.25	1.64	2.2
ci. Observation	Debris Disks and	/SOs									δλ (μμ) . (μασ)	0.06 6.7	0.14 8.8	0.14 11.6	0.15 14.1	0.12 16.6	0.12 19.4	0.16 23.5	0.29 30.8	0.3 41.
										7.7.4	(µио)	0.7	0.0	11.0					30.0	41.
Science Hi	igh-order Erre	ors (LG	S Mod	ie)		Wavefr		Pa	arame	eter					Stre	hl Rat	io (%)			
		_ `		· .	-	Error (r	ms)													
	ric Fitting Error						nm		ubaps											
Bandwidth	n Error						nm nm	51 H 50 W	z (-3db)											
	r Measurement Erro graphy Error						nm nm	4 sc	i beaco	n(s)										
Asterism D	Deformation Error					16	nm	0.50 m	LLT											
Chromatic	Error Displacement Erro	r					nm nm		pper limi stimate	π										
Multispect	tral Error					16	nm	30 ze	en; sci w											
Scintillatio WFS Scinti	on Error illation Error		ľ				nm nm		cint inde		.5um									
				114	nm															
	able Static Telescop able Dynamic Telesc						nm nm		cts Acro ekens P		pil									
Static WFS	Zero-point Calibrat	ion Error				25	nm	A	llocation											
Dynamic V	VFS Zero-point Calib grator Zero-point Ca	ration Err	or Erro-				nm	A	llocation											
	grator Zero-point Ca Instructor Error	nontation	PLIOI.				nm nm		llocation llocation											
Go-to Cont	trol Errors						nm		location											
Residual N	la Layer Focus Chan Stroke Errors	ge					nm nm		/s Nala n P-P si											
DM Hyster	resis					13	nm	fre	om TMT											
	r Aliasing Error Digitization						nm nm	60 S 16 bi	ubaps ts	-										
Uncorrecta	able AO System Abe					33	nm	A	llocation											
	able Instrument Abe						nm nm		AVINCI llocation											
	islet Misregistration islet Pupil Scale Erro						nm		llocation											
				96 r	nm			1.0 ar												
Angular Ar	nisoplanatism Error					16	nm													
	ont Error Margin					45	nm		llocation											
HO Wavefro		_					nm	A	llocation											
HO Wavefro	ont Error Margin ligh Order Wa	vefror	t Erro	T 149 r	nm	45 157			llocation		ehl	0.00	0.01	0.08	0.18	0.29	0.41	0.54	0.70	0.8
Total H	ligh Order Wa	vefror	t Erro	Angul			nm	High	Orde	r Str	ehl	0.00	0.01	0.08			0.41 os (%)		0.70	0.8
Total H		vefror			lar	157	nm ent	High	llocation	r Str	ehl	0.00	0.01	0.08					0.70	0.8
Total H	ligh Order Wa		Sci Filter	Angul Error (r	lar ms)	157 Equiva WFE (ri	nm ent ns)	High Pa	Orde	r Str eter	ehl	0.00	0.01	0.08					0.70	0.8
Total H Science Ti Tilt Measu Tilt Bandwi	igh Order Wa	axis)		Angul Error (r	mas	157 Equiva WFE (ri	ent ns)	Pa 16.0 m 10.1 H	Order	r Str eter	ehl	0.00	0.01	0.08					0.70	0.8
Total H Science Ti Tilt Measu Tilt Bandwi Tilt Anisop	ip/Tilt Errors ip/Tilt Errors irrement Error (one-axis) planatism Error (one	axis)		0.32 r 1.21 r 0.00 r	mas mas	Equiva WFE (ru	ent ns)	Pa 16.0 m 10.1 H 0.0 at	Order	r Str eter	ehl	0.00	0.01	0.08					0.70	0.8
Total H Science Ti Tilt Measu Tilt Bandwi Tilt Anisop Residual C Residual A	ip/Tilt Errors rement Error (one-axis) alanatism Error (one- lentroid Anisoplana atmospheric Dispers	axis) -axis) tism		Angul Error (r 0.32 r 1.21 r 0.00 r 0.55 r 1.47 r	mas mas mas mas mas	157 Equiva WFE (ri	nm lent ns)	16.0 m 10.1 H 0.0 as 20 x	Order	eter	ehl	0.00	0.01	0.08					0.70	0.8
Total H Total H Tilt Measu Tilt Bandwi Tilt Anisop Residual C Residual A Induced PI	ip/Tilt Errors ip/Tilt Error (one-axis) clanatism Error (one-entroid Anisoplana timospheric Dispers late Scale Deformat	axis) -axis) tism ion	Sci Filter	Angul Error (r 0.32 r 1.21 r 0.00 r 0.55 r 1.47 r 0.00 r	mas mas mas mas mas mas	157 Equiva WFE (rr	nm ent ns)	16.0 m 10.1 H 0.0 au 20 x 20 x	Order arame ag (mV) z (-3db) csec fro reduction	eter	ehl	0.00	0.01	0.08					0.70	0.8
Total H Total H Tilt Measu Tilt Bandwi Tilt Anisop Residual A Induced PI Non-Comr Residual T	high Order Wa ip/Tilt Errors irement Error (one-axis) olanatism Error (one ichtroid Anisoplana thmospheric Dispers late Scale Deformat mon-Path Tip-Tilt Er elescope Pointing I	-axis) tism ion ions	Sci Filter	0.32 r 1.21 r 0.00 r 0.55 r 1.47 r 0.00 r 0.27 r 1.14 r 1.	mas mas mas mas mas mas mas mas	157 Equival WFE (ru	nm lent ns)	16.0 m 10.1 H 0.0 ar 20 x 0 m 3.2 mas/lA	Order arame ag (mV) z (-3db) csec fro reduction	eter		0.00	0.01	0.08					0.70	0.8
Total H Science Ti Tilt Measu Tilt Bandwi Tilt Anisop Residual A Induced PI Non-Comr	high Order Wa ip/Tilt Errors irement Error (one-axis) olanatism Error (one ichtroid Anisoplana thmospheric Dispers late Scale Deformat mon-Path Tip-Tilt Er elescope Pointing I	-axis) tism ion ions	Sci Filter	Angul Error (r 0.32 r 1.21 r 0.00 r 0.55 r 1.47 r 0.00 r	mas mas mas mas mas mas mas mas	157 Equiva WFE (ru	nm ent ns) nm nm nm nm nm	16.0 m 10.1 H 0.0 at 20 x 20 x 0 m 3.2 mas/hA	Order arame ag (mV) z (-3db) csec fro reduction reduction conj he	m sci		0.00	0.01	0.08					0.70	8.0
Total H Total H Tilt Measu Tilt Anisop Residual C Residual I Induced PI Non-Comm Residual T T Error Me	igh Order Wa ip/Tilt Errors ip/Tilt Error (one-axis) planatism Error (one exis) planatism Error (one exis) planatism Error (one exist) planatism Error (one exist) planati	-axis) tism ion ions rors	Sci Filter	Angul Error (r 0.32 r 0.00 r 0.55 r 1.47 r 0.00 r 0.27 r 1.14 r 2.00 r	mas	157 Equiva WFE (ri	nm ent ns) nm	16.0 m 10.1 H 0.0 ar 20 x 20 x 20 m 3.2 mss/l A	Order arame ag (mV) z (-3db) cesec fro reduction conj he llocation z input of	m sci	bance				Streh	nl rati	os (%)			
Total H Total H Tilt Measu Tilt Measu Tilt Anisop Residual C Residual C Residual T TT Error Me	high Order Wa ip/Tilt Errors irement Error (one-axis) olanatism Error (one ichtroid Anisoplana thmospheric Dispers late Scale Deformat mon-Path Tip-Tilt Er elescope Pointing I	-axis) tism ion ions rors	Sci Filter	0.32 r 1.21 r 0.00 r 0.55 r 1.47 r 0.00 r 0.27 r 1.14 r 1.	mas	157 Equiva WFE (ri	nm lent ns) nm nm nm nm nm nm	16.0 m 10.1 H 0.0 ar 20 x 20 x 20 m 3.2 mss/l A	Order arame ag (mV) z (-3db) csec fro reduction conj he llocation z input e	m sci	bance					nl rati	os (%)			
Total H Total H Tilt Measu Tilt Measu Tilt Bandwh Tilt Anisop Residual C Residual A Induced P Non-Comr Residual T T Error Me	ligh Order Wa ip/Tilt Errors irement Error (one-axis) Janatism Error (one-fortroid Anisoplana tmospheric Dispers tale Scale Deformat mon-Path Tip-Tilt Er- elescope Pointing J argin ip/Tilt Error (axis) -axis) tism ion ions rors itter (one-	Sci Filter I' axis)	Angul Error (r 0.32 r 0.00 r 0.55 r 1.47 r 0.00 r 0.27 r 1.14 r 2.00 r	mas	157 Equiva WFE (ri	ent ms) nm nm nm nm nm nm nm nm	16.0 m 10.1 H 0.0 at 20 x 20 x 20 x 10 m 3.2 mss/lA 29 H	Order	m sci	bance	0.49	0.62	0.74	Streh	0.86	os (%)	0.92	0.95	0.9
Total H Total H Tilt Measu Tilt Measu Tilt Bandwh Tilt Anisop Residual C Residual A Induced P Non-Comr Residual T T Error Me	igh Order Wa ip/Tilt Errors ip/Tilt Error (one-axis) planatism Error (one exis) planatism Error (one exis) planatism Error (one exist) planatism Error (one exist) planati	axis) -axis) tism ion ions rors itter (one-	Sci Filter I' axis)	Angul Error (r 0.32 r 0.00 r 0.55 r 1.47 r 0.00 r 0.27 r 1.14 r 2.00 r	mas	157 Equiva WFE (ri	ent ms) nm nm nm nm nm nm nm nm	16.0 m 10.1 H 0.0 at 20 x 20 x 20 x 10 m 3.2 mss/lA 29 H	Order arame ag (mV) z (-3db) cesec fro reduction conj he llocation z input of	m sci	bance	0.49	0.62	0.74	Streh	0.86	os (%)	0.92	0.95	0.9
Total H Total H Tit Measu Tit Bandwi Tit Aniso Residual A Induced PI Non-Comr Residual T TT Error Me	ligh Order Wa ip/Tilt Errors irement Error (one-axis) Janatism Error (one-fortroid Anisoplana tmospheric Dispers tate Scale Deformat mon-Path Tip-Tilt Er- elescope Pointing J argin ip/Tilt Error (axis) -axis) tism ion ions rors itter (one-	Sci Filter I' axis)	Angul Error (r 0.32 r 0.00 r 0.55 r 1.47 r 0.00 r 0.27 r 1.14 r 2.00 r	mas	157 Equiva WFE (ri	ent ms) nm nm nm nm nm nm nm nm	16.0 m 10.1 H 0.0 at 20 x 20 x 20 y 1 Tip.	Order	r Str eter) m sci on on eight n	pance	0.49	0.62	0.74	Streh	0.86 0.25	os (%)	0.92	0.95	0.9
Total H Total H Tit Measu Tit Bandwi Tit Aniso Residual A Induced PI Non-Comr Residual T TT Error Me	ligh Order Wa ip/Tilt Errors irement Error (one-axis) Janatism Error (one-fortroid Anisoplana tmospheric Dispers tate Scale Deformat mon-Path Tip-Tilt Er- elescope Pointing J argin ip/Tilt Error (axis) -axis) tism ion ions rors itter (one-	Sci Filter I' axis)	Angul Error (r 0.32 r 1.21 r 0.00 r 0.55 s 1.47 r 0.00 r 0.27 r 1.14 r 2.00 r	mas mas mas mas mas mas mas mas mas mas	157 Equiva WFE (r) 5 21 0 9 27 7 0 5 19 66	nm lent ms) nm	16.0 m 10.1 H 0.0 at at 20 x 20 x 0 m 3.2 mas/1A 29 H Tip.	Order arame ag (mV) (2 (-3db) cosec for reduction for the property of	m sci on on ight n 6treh mas	ni (%)	0.49	0.62	0.74	0.81 0.14	0.86 0.25	0.89 0.36	0.92	0.95	0.9
HO Wavefin Total H Total H Tilt Measu Tilt Bandwi Tilt Aniso Residual C Residual C Residual T TT Error M Total T	iligh Order Wei ip/Tilt Errors rement Error (one-terror (one-terror (one-terror (one-terror one-terror (one-terror one-terror one-	axis) -axis) tism ion ions rors itter (one-	Sci Filter I' axis)	Angul Error (r 0.32 r 1.21 r 0.00 r 0.55 s 1.47 r 0.00 r 0.27 r 1.14 r 2.00 r	mas mas mas mas mas mas mas mas mas mas	157 Equiva WFE (r) 5 21 0 9 27 7 0 5 19 66	nm lent ms) nm	16.0 m 10.1 H 0.0 at 20 x 20 x 20 y 1 Tip.	Order arame (mV) ag (mV) cy (-3db) cy (m sci on on eight n ftreh mas	35	0.49 0.00 7.4	0.62 0.01 9.3	0.74 0.06 12.0	0.81 0.14 14.4	0.86 0.25 16.9	0.89 0.36 19.7	0.92 0.50 23.7	0.95	0.9 0.8 41.
Total H Total H Tit Measu Tilt Bandwi Tilt Andrew Tilt Andrew Residual C Residual C Residual T TT Error M Total T	iligh Order Wei ip/Tilt Errors rement Error (one-terror (one-terror (one-terror (one-terror one-terror (one-terror one-terror one-	axis) -axis) tism ion ions rors itter (one-	Sci Filter	Angul Error (r 0.32 r 1.21 r 0.00 r 0.55 s 1.47 r 0.00 r 0.27 r 1.14 r 2.00 r	mas mas mas mas mas mas mas mas mas mas	157 Equiva WFE (r) 5 21 0 9 27 7 0 5 19 66	nm lent ms) nm	## High 1 16.0 m 10.1 0.0 at 20 x 20 x	Ordel arame ag (mV) g (-3db) cosee for reducting reduction red	m sci on on on eight on mas itsi	ni (%)	0.49	0.62 0.01 9.3 70 0.19	0.74	0.81 0.14	0.86 0.25 16.9 240 0.30	0.89 0.36	0.92	0.95	0.9
HO Wavefin Total H Science T ii Tilt Measu Tilt Measu Tilt Anisop Residual C Residual C Residual T Induced PI Non-Comm Residual T T T Enro M T Total T	ligh Order Wei IghT lit Errors rement Error (one- den Error	axis) -axis) tism ion ions rors itter (one-	Sci Filter	Angul Error (r 0.32 r 1.21 r 0.00 r 0.05 s 1.47 r 0.00 r 0.05 r 1.44 r 1.40 r 1.41 r 2.00 r 3.1 l	mas	157 Equiva WFE (ri 5 21 0 9 27 7 0 66 55 165	nm ent ms) nm nm nm nm nm nm nm nm nm	High 16.0 m 10.1 H 0.0 at 20 x 20 x 20 x 10 m A 29 H A Tip. Tota	Ordel arame ag (mV) g (-3db) cosee for reducting reduction red	m sci pon pon eight n mehl (streh	35 0.18	0.49 0.00 7.4 50 0.19	0.62 0.01 9.3 70 0.19	0.74 0.06 12.0 90 0.20	0.81 0.14 14.4	0.86 0.25 16.9 240 0.30	0.89 0.36 19.7 400 0.42	0.92 0.50 23.7 800 0.63	0.95	0.9 0.8 41.
Total H Total H Tit Measu Tilt Bandwi Tilt Andrew Tilt Andrew Residual C Residual C Residual T TT Error M Total T	ligh Order Wei IghT lit Errors rement Error (one- den Error	axis) -axis) tism ion ions rors itter (one-	Sci Filter	Angul Error (r 0.32 r 1.21 r 0.00 r 0.55 s 1.47 r 0.00 r 0.27 r 1.14 r 2.00 r	mas	157 Equiva WFE (ri 5 21 0 9 27 7 0 66 55 165	nm lent ms) nm	High 16.0 m 10.1 H 0.0 at 20 x 20 x 20 x 10 m A 29 H A Tip. Tota	Ordel arame ag (mV) g (-3db) cosee for reducting reduction red	m sci pon pon eight n mehl (streh	35 0.18	0.49 0.00 7.4 50 0.19	0.62 0.01 9.3 70 0.19	0.74 0.06 12.0 90 0.20	0.81 0.14 14.4	0.86 0.25 16.9 240 0.30	0.89 0.36 19.7 400 0.42	0.92 0.50 23.7 800 0.63	0.95	0.9 0.8 41,
HO Wavefin Total H Titt Measu Tilt Measu Tilt Measu Tilt Anisop Residual C Residual A Induced PI Non-Comm Residual T TT Emor Me Total T	ligh Order Wei ight Content of the C	nt Erro	Sci Filter	Angul Error (r 0.32 r 1.21 r 0.00 r 0.05 s 1.47 r 0.00 r 0.05 r 1.44 r 1.40 r 1.41 r 2.00 r 3.1 l	mas	157 Equiva WFE (ri 5 21 0 9 27 7 0 66 55 165	nm ent ms) nm nm nm nm nm nm nm nm nm	High 16.0 m 10.1 H 0.0 at 20 x 20 x 20 x 10 m A 29 H A Tip. Tota	Order Or	m sci on on eight n mas	35 0.18	0.49 0.00 7.4 50 0.19 0.01	0.62 0.01 9.3 70 0.19 0.01	0.74 0.06 12.0 90 0.20 0.02	0.81 0.14 14.4 120 0.22 0.04	0.86 0.25 16.9 240 0.30 0.13	0.89 0.36 19.7 400 0.42	0.92 0.50 23.7 800 0.63	0.95	0.9 0.8 41,
Total H Total H Tit Measu Tilt Measu Tilt Measu Tilt Anisop Residual C Residual A Induced PI Non-Comm Residual T TT Emor Me Total T	ligh Order Wei igh Tilt Errors rement Error (one-to-to-to-to-to-to-to-to-to-to-to-to-to-	-axis) -axis) sism ion ion rors ttter (one- The Erro Cover	Sci Filter	Angul Error (r 0.32 r 1.21 r 0.00 r 0.05 s 1.47 r 0.00 r 0.05 r 1.44 r 1.40 r 1.41 r 2.00 r 3.1 l	mas	157 Equiva WFE (ri 5 5 21 0 0 9 19 19 666 666 555 165	nm ent ms) nm nm nm nm nm nm nm nm nm	High Pi 15.0 mm 15	Order Or	m sci on on eight n mas	35 0.18	0.49 0.00 7.4 50 0.19 0.01	0.62 0.01 9.3 70 0.19 0.01	0.74 0.06 12.0 90 0.20 0.02	0.81 0.14 14.4 120 0.22 0.04	0.86 0.25 16.9 240 0.30 0.13	0.89 0.36 19.7 400 0.42	0.92 0.50 23.7 800 0.63	0.95	0.9 0.8 41,
Total H Total H Tit Measu Tilt Measu Tilt Measu Tilt Anisop Residual C Residual A Induced PI Non-Comm Residual T TT Emor Me Total T	ligh Order Wei ight Content of the C	-axis) -axis) sism ion ion rors ttter (one- The Erro Cover	Sci Filter	Angul Error (r 0.32 r 1.21 r 0.00 r 0.05 s 1.47 r 0.00 r 0.05 r 1.44 r 1.40 r 1.41 r 2.00 r 3.1 l	mas	157 Equiva WFE (ri 5 5 21 0 0 9 19 19 666 666 555 165	nm ent ms) nm nm nm nm nm nm nm nm nm	High Pi 15.0 mm 15	Order Or	m sci on on eight n mas	35 0.18	0.49 0.00 7.4 50 0.19 0.01	0.62 0.01 9.3 70 0.19 0.01	0.74 0.06 12.0 90 0.20 0.02	0.81 0.14 14.4 120 0.22 0.04	0.86 0.25 16.9 240 0.30 0.13	0.89 0.36 19.7 400 0.42	0.92 0.50 23.7 800 0.63	0.95	0.9 0.8 41,
Total H Total H Titt Measu Tilt Bandwi Tilt Anisop Residual C Residual A Induced PI Non-Comr Residual T TT Emr Me Total T	ligh Order We ip/T ilt Errors rement Error (one-ic one-ic one-i	axis) -axis) -axis) itism ion ion ons ors itter (one- ax Cover	Sci Filter	Angul Error (r 0.32 r 1.21 r 0.00 r 0.05 r 0.00 r 0.00 r 1.14 r 2.00 r 3.1 l	mas	157 Equiva WFE (ri 5 21 0 9 9 27 10 6 66 66 165 165 22%	nm ent ent ms) nm nm nm nm nm nm nm nm nm deg	High Pi	Order Or	m sci on on eight n mas	35 0.18	0.49 0.00 7.4 50 0.19 0.01	0.62 0.01 9.3 70 0.19 0.01	0.74 0.06 12.0 90 0.20 0.02	0.81 0.14 14.4 120 0.22 0.04	0.86 0.25 16.9 240 0.30 0.13	0.89 0.36 19.7 400 0.42	0.92 0.50 23.7 800 0.63 0.78	0.95	0.9 0.8 41,
Total H Total H Tilt Measu Tilt Measu Tilt Bandwi Tilt Anisop Residual C Residual A Induced PI Non-Comr Residual T TT Error Me Total T otal Effect nsquarec corres ssumptio	ligh Order Wei Ight It Errors rement Error (one-to-ensure) and Error (one-to-ensure) Indianatism Fror (o	wis) axis) axis) isism ion ion ion one-ax tter (one-ax tter (one-ax covers meters 33	sci filter	Angul Error (r 0.32 r 1.21 r 0.00 r 0.05 r 0.00 r 0.00 r 1.14 r 2.00 r 3.1 l	lar ms) mas	157 Equiva WFE (ri) 5 5 21 21 20 20 20 20 20 20 20 20 20 20 20 20 20	nm ent ms) nm	High Pi	Order arama ag (mV.) ag	m sci on on pon eight n n Streh 1.11 0.00	35 0.18	0.49 0.00 7.4 50 0.19 0.01	0.62 0.01 9.3 70 0.19 0.01 Total E#	0.74 0.06 12.0 90 0.20 0.02	0.81 0.14 14.4 120 0.22 0.04	0.86 0.25 16.9 240 0.30 0.13	0.89 0.36 19.7 400 0.42	0.92 0.50 23.7 800 0.63 0.78	0.95	0.6 0.8 41 51 0.5
Total H Total H Titt Measu Tilt Bandwi Tilt Anisop Residual C Residual A Induced PI Non-Comr Residual T TT Emr Me Total T	ligh Order Wei igh Title Errors rement Error (one- deh Error	cover	sci filter	Angul Error (r 0.32 r 1.21 r 0.00 r 0.05 r 0.00 r 0.00 r 1.14 r 2.00 r 3.1 l	mas	157 Equiva WFE (ri 5 21 0 9 9 27 10 6 66 66 165 165 22%	nm ent ms) nm	High Pi	Order Or	m sci on on pon eight n n Streh 1.11 0.00	35 0.18	0.49 0.00 7.4 50 0.19 0.01	0.62 0.01 9.3 70 0.19 0.01 Total E#	0.74 0.06 12.0 90 0.20 0.02	0.81 0.14 14.4 120 0.22 0.04	0.86 0.25 16.9 240 0.30 0.13	0.89 0.36 19.7 400 0.42 0.33	0.92 0.50 23.7 800 0.63 0.78	0.95	0.6 0.8 41 51 0.5
Total H Total H Titt Measu Tilt Bandwi Tilt Anisop Residual C Residual A Induced PI Non-Comr Residual T TT Emr Me Total T	ligh Order Wei igh Title Errors rement Error (one- deh Error	Location (Covered Services) (Cov	Sci Filter // -axis) is) r age deg m marssec m/s	Angul Error (r 0.32 r 1.21 r 0.00 r 0.05 r 0.00 r 0.00 r 1.14 r 2.00 r 3.1 l	lar ms) mas	### 1577 Equivalent Fig.	nm ent ms) nm	High	Illocation Order arame (mV) (a (-3db) cose for reductir reductir con he he lillocation (llocation Tilt S HHM (note) (a con he he lillocation (b con he lillocation (con he lillocation (m sci on m s	35 0.18 0.00	0.49 0.00 7.4 50 0.19 0.01 LO WFS 17.0 Derived	0.62 9.3 70 0.19 0.01 Total Eff	0.74 0.06 12.0 90 0.20 0.02 des 15.3	0.81 0.14 14.4 120 0.22 0.04	0.86 0.25 16.9 0.13	0.89 0.36 19.7 400 0.42 0.33	0.92 0.50 23.7 800 0.63 0.78	0.95	0.6 0.8 41 51 0.5
Total H Total H Tilt Measu Tilt Measu Tilt Bandwi Tilt Anisop Residual C Residual A Induced PI Non-Comr Residual T TT Error Me Total T otal Effect nsquarec corres ssumptio	ligh Order Wei igh Tilt Errors rement Error (one-to-to-to-to-to-to-to-to-to-to-to-to-to-	axis) -axis) -axis) -axis) -axis) -axis) -axis) -axis) -axis) -axis -axi	Sci Filter // // // axis) // // // // // // // // //	Angulus Angulu	mas	157 Equiva WFE (ri	nm ent ms) nm	High	Illocation Order Tribe Illocation Tribe Illocation Tribe Illocation Tribe On of sky	m scion on on eight n disturt n streh i.11100	35 0.18	0.49 0.00 7.4 50 0.19 0.01 LO WFS 17.0 Derived	0.62 9.3 70 0.19 0.01 Total Eff	0.74 0.06 12.0 90 0.20 0.02 des 15.3	0.81 0.14 14.4 120 0.22 0.04	0.86 0.25 16.9 240 0.30 0.13	0.89 0.36 19.7 400 0.42 0.33	0.92 0.50 23.7 800 0.63 0.78	0.95	0.8 0.8 41 51 0.5
Total H Total H Tit Measu Tilt Measu Tilt Bandwi Tilt Anisop Residual C Residual A Induced PI Non-Comr Residual T TT Error Me Total T Total T Cotal Effect Residual A Atmosphe	ligh Order Wei Igh Tilt Errors rement Error (one-i- mement Error (one-	axis) -axis) -axis) -axis) -axis) -axis) -axis) -axis) -axis) -axis -axi	Sci Filter // -axis) is) r age deg m marssec m/s	Angulus Angulu	lar ms) mas	### 157 Equiva WFE (rival) 5	ent ms) nm	High	Order Or	m scion on on eight n disturt n streh i.11100	35 0.18 0.00	0.49 0.00 7.4 50 0.01 0.01 LO WFS 17.0 Derived	0.62 0.01 9.3 70 0.19 0.01 Total Ethorough	0.74 12.0 90 0.20 0.02 des 15.3	0.81 0.14 14.4 120 0.22 0.04	0.86 0.25 16.9 240 0.30 0.13	0.89 0.36 19.7 400 0.42 0.33	0.92 0.50 23.7 800 0.63 0.78	0.95	0.8 0.8 41 51 0.5
Total H Total H Titt Measu Tilt Bandwi Tilt Anisop Residual C Residual A Induced PI Non-Comr Residual T T E mor Me Total T	ligh Order Wei igh Title Errors rement Error (one- deh Error	cover see see see see see see see see see s	Sci Filter // // // axis) // // // // // // // // //	Angulus Angulu	lar mms) mmas mmas mmas mmas mmas mmas mmas	### 157 Equivalent Fig. F	nm ent ms) nm	High	Order Order ag (mVV) ag (mVV) c (-3db) csse for conj he libraria conj he libra	m sci on on eight on the sci t	35 0.18 0.00	0.49 0.00 7.4 50 0.19 0.01 LO WFS 17.0 Derived	0.62 0.01 9.3 70 0.19 0.01 Total E8 HO WFS Detected	0.74 0.06 12.0 90 0.20 0.02 15.3 Rate 15 PDE/s	0.81 0.14 14.4 120 0.22 0.04	0.86 0.25 16.9 240 0.30 0.13	0.89 0.36 19.7 400 0.42 0.33	0.92 0.50 23.7 800 0.63 0.78	0.95	0.9 0.8 41. 51 0.5
Total H Total H Titt Measu Tilt Bandwi Tilt Anisop Residual C Residual A Induced PI Non-Comr Residual T T E mor Me Total T	ligh Order Wei Igh Tilt Errors rement Error (one-i- mement Error (one-	uxis) -axis) sism lism lon onors onors teter (one- axis) sism onors teter (one- axis) con onors onors teter (one- axis) sism onors onors teter (one- axis) sism onors on	Sci Filter P axis) If P deg m arcsec m/s x x 109 cm	Angulus Angulu	lar ms) mas	### 157 Equiva WFE (rival) 5	nm lent ms) nm	High	Order Or	r Str r Str r Str n sci pon pon pon pon pon pon pon po	35 0.18 0.00	0.49 0.00 7.4 50 0.19 0.01 LO WFS 17.0 Derived	0.62 0.01 9.3 70 0.19 0.01 Total E8 HO WFS Detected	0.74 0.06 12.0 90 0.20 0.02 15.3 Rate 15 PDE/s	0.81 0.14 14.4 120 0.22 0.04	0.86 0.25 16.9 240 0.30 0.13	0.89 0.36 19.7 400 0.42 0.33	0.92 0.50 23.7 800 0.63 0.78	0.95	0.6 0.8 41 51 0.5
Total H Total H Titt Measu Tilt Bandwi Tilt Anisop Residual C Residual A Induced PI Non-Comr Residual T T T E mor Me Total T Total T Cotal Effect Cores Corres Lissumptio Atmosphe	ligh Order Wei igh Order Wei ight It Errors rement Error (one-cond) rement Error (one-cond) the free (one-axis) landatism Fror (one-done) interest of the free free free free free free free fr	axis) axis) issm ion ion ions cors itter (one Cover ers 30 0.474 1.097 50 3 3 MOAO indep Pr	Sci Filter P axis) If P deg m arcsec m/s x x 109 cm	Angulus Angulu	lar ms) mas	### 157 Equiva WFE (rival) 5 21 6 21 9 9 7 7 0 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6	nm lent ms) nm	High I Pri- 150 mm I Total Total Search Search This fraction 9	Ordei ag (mV (-3db)) ag (mV (-3db)) ag (mV) ag (mV) ag (mV) ag (mV) ag (mV) Tilt S Ti	r Str r Str r Str m sci pon pon pon pon pon pon pon po	35 0.18 0.00	0.49 0.00 7.4 50 0.19 0.01 LO WFS 17.0 Derived	0.62 0.01 9.3 70 0.19 0.01 Total E8 HO WFS Detected	0.74 0.06 12.0 90 0.20 0.02 15.3 Rate the PDE/s	0.81 0.14 14.4 120 0.22 0.04	0.86 0.25 16.9 240 0.30 0.13	0.89 0.36 19.7 400 0.42 0.33	0.92 0.50 23.7 800 0.63 0.78	0.95	0.9 0.8 41. 51 0.5
Total H Total H Titt Measu Tilt Bandwi Tilt Anisop Residual C Residual A Induced PI Non-Comr Residual T T T E mor Me Total T Total T Cotal Effect Cores Corres Lissumptio Atmosphe	ligh Order Wei igh Order Wei ight It Errors rement Error (one-ic one-ic one-	axis) axis) issm ion ion ions cors itter (one Cover ers 30 0.474 1.097 50 3 3 MOAO indep Pr	Sci Filter P axis) is) r r deg m arcsec m/s m x 109 cm	Angulus Angulu	lar ms) mas	### ##################################	nm lent ms) nm	High I Pri- 150 mm I Total Total Search Search This fraction 9	Order arame ag (mV.) g (-3db) see for for evelution of see for	r Str r Str r Str m sci pon pon pon pon pon pon pon po	35 0.18 0.00	0.49 0.00 7.4 50 0.19 0.01 LO WFS 17.0 Derived	0.62 0.01 9.3 70 0.19 0.01 Total E8 HO WFS Detected	0.74 0.06 12.0 90 0.20 0.02 15.3 Rate the PDE/s	0.81 0.14 14.4 120 0.22 0.04	0.86 0.25 16.9 240 0.30 0.13	0.89 0.36 19.7 400 0.42 0.33	0.92 0.50 23.7 800 0.63 0.78	0.95	0.9 0.8 41. 51 0.5
Total H Total H Titt Measu Tilt Bandwi Tilt Anisop Residual C Residual A Induced PI Non-Comr Residual T T T E mor Me Total T Total T Cotal Effect Cores Corres Lissumptio Atmosphe	iligh Order Wei in Fore (one-ais) ilight order wei in Fore (one-ais) ilight order wei in Fore (one-ais) ilight order ilight	Covers Covers	Sci Filter F axis) is) r deg m arcsec m/s m x 109 cm	Angulus Angulu	lar ms) mas	### 157 Equiva WFE (rival) 5 21 6 21 9 9 7 7 0 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6 6	nm ent ms) nm	High I Pri- 150 mm I Total Total Search Search This fraction 9	Ordei ag (mV (-3db)) ag (mV (-3db)) ag (mV) ag (mV) ag (mV) ag (mV) ag (mV) Tilt S Ti	m sci	35 0.18 0.00	0.49 0.00 7.4 50 0.19 0.01 LO WFS 17.0 Derived	0.62 0.01 9.3 70 0.19 0.01 Total E8 HO WFS Detected	0.74 0.06 12.0 90 0.20 0.02 15.3 Rate the PDE/s	0.81 0.14 14.4 120 0.22 0.04	0.86 0.25 16.9 240 0.30 0.13	0.89 0.36 19.7 400 0.42 0.33	0.92 0.50 23.7 800 0.63 0.78	0.95	0.6 0.8 41 51 0.5

Gas Giant Planets

-punnedt	ions/sky co											550	, 140	AU F	PROP	NIE 17	AIN I			
Purpose:		This work	ksheet wil	Il allow one	to opti	mize sky cove erms; several	rage by	changing	parame	ters	nt to the	nurnio -	plic ha-	,						
						erms; several whether the s														
Solver Inp	out Values	NGS	LGS			Current Sett														
	star brightness integration time:	LGS 0.00050	0.0010	mV sec		53 1020		ubap/exp				e LGS O			N N					
Optim subs	aperture width:	0.174	0.174	meters		60	Subap	s				e Subap			N	0.182	m	Non-opti	m subap	width
TT guide st TT integrati	tar brightness ion time	LGS 0.00050		mV sec			mKs Hz													
TT guide st	tar distance	0.0	30.0	arcsec																
	le star birghtness gration time	LGS 0.0		mV sec		0.50	Hz													
TWFS guid	le star search radius	0.0	30.0	arcsec																
LGS asteris	laser beacons sm radius	0.0	4.0 0.167	arcmin		Set ast rad =	0.001 fi	or single L	.GS		Optimiz	re LGS as	terism ra	adius?	N	< not	yet imple	emented (11/18/08	
Cook Way	vefront Erro	r Dudo	ot Su	mmanı		Version 2.1									Sci	ence	Rand			
Ande:	NGAO LGS	Duug	jet Jui	шиагу		version 2.1						u'	g'	ď	j'	Z	Y	J	Н	K
nstrument:	DAVINCI										λ (μμ)	0.36	0.47	0.62	0.75	0.88	1.03	1.25	1.64	2.20
ci. Observation	Gas Giant Planet	S									δλ (μμ) Δ (μασ)	0.06 6.7	0.14	0.14 11.6	0.15 14.1			0.16 23.5	0.29 30.8	0.34 41.4
										7,77	(μασ)	0.7	0.0	11.0					30.0	41.4
Science H	igh-order Err	ors (LG	S Mod	le)		Wavefr			Paran	neter					Stre	hl Rat	tio (%))		
_	1	<u> </u>		•		Error (r	ms)													
Atmosphe	ric Fitting Error						nm		Subaps											
Bandwidth High-orde	n Error r Measurement Erro	nr.					nm		Hz (-3d W)										
LGS Tomog	graphy Error	,					nm	4	sci bea	con(s)										
Asterism E Chromatic	Deformation Error					16	nm nm		m LLT	mit										
	: Error n Displacement Erro	ır					nm		Upper li Estimat											
Multisped	tral Error						nm		zen; sc		·									
Scintillatio WFS Scinti	on Error illation Error		К				nm	0.34	Scint in Allocati		oum									
				115	nm															
	able Static Telescop able Dynamic Teles						nm		Acts Acts Acts Acts Acts Acts Acts Acts		ihii									
Static WFS	Zero-point Calibra	tion Error				25	nm		Allocati	on										
	VFS Zero-point Cali grator Zero-point C						nm		Allocati Allocati											
Stale Reco	instructor Error					15	nm		Allocati	on										
Go-to Con	trol Errors la Layer Focus Chan	an an					nm	20	Allocati m/s Na		4									
DM Finite	Stroke Errors					6	nm	5.3	um P-P	stroke										
DM Hyster	resis er Aliasing Error					13	nm		from TM Subaps		ı									
	r Aliasing Error Digitization						nm		bits											
Uncorrecta	able AO System Ab						nm		Allocati											
	able Instrument Ab Islet Misregistration						nm		Allocati											
	islet Pupil Scale Err						nm		Allocati	on										
Angular A	nisoplanatism Error			98	nm	63	nm	5.0	arcsec		-									
	ont Error Margin					45	nm		Allocati	on										
Total F	ligh Order Wa	vefron	t Error	151	nm	169	nm	Hial	n Ord	er Sti	rehl	0.00	0.01	0.05	0.14	0.24	0.35	0.49	0.66	0.80
	g c. do. III							g.		<u> </u>	0	0.00	0.01	0.00					0.00	0.00
Science T	ip/Tilt Errors			Angu		Equiva WFE (r			Parar	neter					Stre	hl rati	os (%)		
			Sci Filter	Error (11115)	VVFE (I	1115)													
	rement Error (one-	axis)			mas		nm		mag (m											
	idth Error (one-axis) planatism Error (one	e-axis)			mas mas		nm		Hz (-3d arcsec											
Residual C	entroid Anisoplana	tism		0.55	mas	9	nm	20	x reduc	tion										
	ktmospheric Disper late Scale Deforma		К		mas		nm		x reduc											
Non-Comr	mon-Path Tip-Tilt E	rors		0.00	mas	0	nm	3.2 mas/	Allocat	ion										
Residual T TT Error Ma	'elescope Pointing . argin	itter (one-	axis)		mas		nm	29	Hz inpu Allocat		bance									
				2.00	IIIas	100														
Total T	ip/Tilt Error	one-ax	is)	3.5	mas	66	nm	Ti	p/Tilt	Strel	hl	0.42	0.56	0.69	0.76	0.82	0.86	0.90	0.94	0.97
											-									
otal Effec	tive Wavefro	nt Erro	r			180	nm	То	tal St	rehl (%)	0.00	0.00	0.04	0.10	0.20	0.30	0.44	0.62	0.77
									\A/I -= -		_	7.0	0.5	40.1	11.	47.0	10-	00.0	24.0	44 -
_								<u> </u>	WHM	(mas	5)	7.6	9.5	12.1	14.5	17.0	19.7	23.8	31.0	41.6
				Spa	xel/	Aperture	Dian	neter (mas)	15	35	50	70	90	120	240	400	800		44
nsquared	d Energy		К					Squ	are	0.09	0.35	0.55	0.73			0.84		0.91		0.50
,								Seeing-	Limited	0.00	0.00	0.01	0.02	0.03	0.05	0.20	0.45	0.90		
,		_		Galactic La	titude	N/A	deg			_		_	_				_			
	age						6													
Sky Cover						######		This fract	ion of sk	y can b	e correct	ted to the	Total Ef	fective W	/FE show	m				
Sky Cover	age ponding Sky	Cover	age																_	
Sky Cover			age																	
Corres	ponding Sky	ers	age																	
Corres	ponding Sky ons / Paramet	ers			Systen	Parameters LGS Asterisr	n Radio		0.17	arcmin			Magnitu 4.7		4.2	A1	4.0) 20	3 0	2
Corres	ons / Paramet cric / Observing Para Zenith Angle	ers ameters 30 0.147	deg m		Systen	LGS Asterisr		3	50	arcmin W		6.1	4.7		4.2	4.1	4.0	3.8	3.5	3
Corres	ponding Sky ons / Parameteric / Observing Para Zenith Angle 10 theta0_eff	ers ameters 30 0.147 2.145	deg m arcsec		Systen	LGS Asterisr LGS Power BTO Transmi	ssion		50 0.60	arcmin W		6.1	4.7 Values	4.3				3.8	3.5	3
Corres	ons / Paramet cric / Observing Para Zenith Angle	meters 30 0.147 2.145 10.97 50	deg m arcsec m/s		Systen	LGS Asterism LGS Power BTO Transmi HO WFS Tra HO WFS Typ	ssion nsmissi e		0.60 0.38 SH	Wusing	CCID74	6.1	4.7 Values HO WFS	4.3 Rate		1020	Hz	3.8	3.5	3
Corres	ponding Sky ons / Parameteric / Observing Para Zenith Angle ro theta0_eff Wind Speed	meters 30 0.147 2.145 10.97 50	deg m arcsec m/s	-2	Systen	LGS Asterism LGS Power BTO Transmi HO WFS Tra HO WFS Typ HO WFS Noi:	ssion nsmissi ie	on	50 0.60 0.38 SH 1.8	W	CCID74	6.1	4.7 Values HO WFS	4.3 Rate		1020	Hz	3.8	3.5	3
Corres Corres Atmosphe	ponding Sky ons / Paramet pric / Observing Par. Zenith Angle ro theta0_eff Wind Speed Outer Scale Sodium Abundanc	meters 30 0.147 2.145 10.97 50	deg m arcsec m/s	-2	System	LGS Asterism LGS Power BTO Transmi HO WFS Tra HO WFS Typ	ssion nsmissi e se i-aliasin	on g	0.60 0.38 SH	Wusing	CCID74	6.1	4.7 Values HO WFS	4.3 Rate d PDE/s		1020	Hz	3.8	3.5	3
Corres Corres Assumptio	ponding Sky ons / Paramet ric / Observing Par Zenith Angle r0 theta0_eff Wind Speed Outer Scale Sodium Abundano of Operation Science AO Mode	ers 30 0.147 2.145 10.97 50 3 3	deg m arcsec m/s m x 109 cm	2	Systen	LGS Asterior LGS Power BTO Transmi HO WFS Tra HO WFS Typ HO WFS Ant LO WFS Tran LO WFS Type	ssion nsmissi e se i-aliasin smissio	on g	50 0.60 0.38 SH 1.8 NO 0.29	using e- rms using		6.1	4.7 Values HO WFS Detecte	4.3 Rate d PDE/s		1020 53	Hz Hz	3.8	3.5	3
Corres Corres Assumptio	ponding Sky ons / Paramel ric / Observing Par Zenith Angle rio theta0_eff Wind Speed Outer Scale Sodium Abundano of Operation	ers 30 0.147 2.145 10.97 50 3 3	deg m arcsec m/s m x 109 cm	-2	Systen	LGS Asterism LGS Power BTO Transmi HO WFS Tra HO WFS Typ HO WFS Ant LO WFS Tran LO WFS Type LO WFS Nois	ssion nsmissi e se i-aliasin smissio	on g	50 0.60 0.38 SH 1.8 NO 0.29 SH 3.2	using e- rms using e- rms		6.1	4.7 Values HO WFS Detecte	4.3 Rate d PDE/s	ubap/exp	1020 53	Hz Hz	3.8	3.5	3
Corres Assumptic Atmosphe	ponding Sky ons / Paramet ric / Observing Par Zenith Angle r0 theta0_eff Wind Speed Outer Scale Sodium Abundano of Operation Science AO Mode	30 0.147 2.145 10.97 50 3 3 : MOAO Indep Pn	deg m arcsec m/s m x 109 cm	2	System	LGS Asterior LGS Power BTO Transmi HO WFS Tra HO WFS Typ HO WFS Ant LO WFS Tran LO WFS Type	ssion nsmissi e se i-aliasin smissio e Type:	g n	50 0.60 0.38 SH 1.8 NO 0.29	using e- rms using e- rms		6.1	4.7 Values HO WFS Detecte	4.3 Rate d PDE/s	ubap/exp	1020 53	Hz Hz	3.8	3.5	3
Corres Assumptic Atmosphe	ponding Sky Dns / Paramet Inc / Observing Par Zenith Angle To theta0_eff Wind Speed Outer Scale Sodium Abundano of Operation Science AO Mode: UWFS AO Mode: TT WS for TT meas	2015 2016 20147 20145 10.97 500 2016	deg m arcsec m/s m x 109 cm	-2		LGS Asterisr LGS Power BTO Transmil HO WFS Tra HO WFS Typ HO WFS Noi: HO WFS Ant LO WFS Tran LO WFS Type LO WFS Noi: LO WFS Star Max TT Reject	ssion nsmissi e se i-aliasin smissio e Type:	g n	50 0.60 0.38 SH 1.8 NO 0.29 SH 3.2 G	using e- rms using e- rms		6.1	4.7 Values HO WFS Detecte	4.3 Rate d PDE/s	ubap/exp	1020 53	Hz Hz	3.8	3.5	3
Corres Assumptic Atmosphe	ponding Sky ons / Paramet ric / Observing Par Zenith Angle rio theta0_eff Wind Speed Outer Scale Sodium Abundano of Operation Science AO Mode LOWFS AO Mode: WFS's for TT meas	meters 30 0.147 2.145 10.97 50 3 3 3 : MOAO Indep Pn	deg m arcsec m/s m x 109 cm	2		LGS Asterish LGS Power BTO Transmi HO WFS Tra HO WFS Tro HO WFS Noi: HO WFS Ant LO WFS Tran LO WFS Trype LO WFS Nois LO WFS Star	ssion nsmission se i-aliasin smissio e Type: ction Ba	g n	50 0.60 0.38 SH 1.8 NO 0.29 SH 3.2 G	using e- rms using e- rms		6.1	4.7 Values HO WFS Detecte	4.3 Rate d PDE/s	ubap/exp	1020 53	Hz Hz	3.8	3.5	3

Ice Giant Planets



Appendix B: Atmospheric Turbulence Assumptions

The following are detailed wavefront error / ensquared energy budgets developed using the median turbulence condition Mauna Kea Ridge $C_n^2(h)$ model (KAON 503). This model has:

$$r_0 \, (0.5 \ microns) = 16 \ cm$$

$$\theta_0 \, (0.5 \ microns) = 2.7 \ arcseconds$$

$$d_0 \, (0.5 \ microns) = 4.85 \ m$$

$$L_0 = 50 \ m$$

with a $C_n^2(h)$ distribution given by:

Altitude (m)	Mauna Kea Ridge Cn2 Fractional Turbulence
0	0.517
500	0.119
1000	0.063
2000	0.061
4000	0.105
8000	0.081
16000	0.054

KAON 503 also defines a wind velocity model for the Mauna Kea Ridge resulting in:

Greenwood frequency = 27.91 Hz